LIFE-CYCLE ANALYSIS -

A CHALLENGE FOR FORESTRY

AND FOREST INDUSTRY

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FOREWORD

The achievements and problems of Life Cycle Analysis (LCA) in forestry and forest products industry were the focus points of an international workshop held in May 1995 in Hamburg. This workshop was organised jointly by the Federal Research Centre for Forestry and Forest Products (Germany) and the European Forest Institute (EFI). It gathered over 40 experts from 12 countries, European Commission, International Institute for Applied Systems Analysis (IIASA) and EFI.

The workshop presentations included, besides LCA studies, projects which take into account specific parts of environmental judgement, such as eco-balancing, environmental declaration, environmental performance studies and eco-labelling. LCA was found to be an ambiguous tool for approaching environmental problems associated with the provision of goods and services, but seems to have the possibilities for fulfilling the demands from the scientific point of view under the aspects of comprehensiveness, accuracy and comparability. However, the methodology for LCA is far from being completely developed.

The workshop recommended methodology development through international co-operation, establishing an international group on LCA in forestry and forest industry, and follow-up workshops. More intensive co-operation is needed between industry and research - LCA is, to a great extent, based on data provided by the industry while its results are aimed at the industry as well as to policy-makers and society as a whole. A commonly agreed integrated database for different levels and activities were seen important as well as linking the LCA approach with economic considerations and markets.

These proceedings include 22 papers presented at the workshop, and we hope they could form a constructive basis for further discussion and progress within this field. We would like to thank all participants of the workshop, and the Federal Research Centre for Forestry and Forest Products for excellent technical and social arrangements.

Finally, we thank the European Commission DG XII and the Nordic Academy for Advanced Study (NorFA) for their financial support which made the workshop possible. This event was special, as it was the first meeting NorFA financed outside the Nordic countries.

Hamburg and Joensuu, December 1995.

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Introduction - LCA in Forestry

LCA - A CHALLENGE FOR FORESTRY AND FOREST PRODUCTS INDUSTRY

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Abstract

This paper describes the problem areas dealt with in the workshop. The reader should not expect any problem solution, rather, the identified problems should be seen as challenges.

Introduction

Environmental issues have gained public awareness in most countries. The Rio Declaration and the recent conference in Berlin on climate changes have shown the broad interest of the society and policy makers in these issues. Besides global warming, other key-words in the ecological discussion are: resource management, environmentally friendly energy supply systems, eco-toxicology and human health. In the light of resource management recycling has enjoyed a dynamic development.

Among other tools for the assessment of the impacts of mankind's activities on the environment, the instrument of LCA-Life Cycle Assessment has found considerable interest. LCA of products or services are of interest for both the manufacturer of goods or provider of services as well as for the consumer of goods or services.

LCA studies can be used in the scientific or traditional way as an internal (i.e. factory internal) tool to improve the product or the process towards smaller impact on the environment. The reduction of the impact could be through changes in raw material use, the manufacturing process, during product use, and after product use.

LCA-studies can also be used in a more progressive way, externally as a marketing instrument. Products fulfilling similar functions could be made of different raw material and/or manufactured in different processes. A comparative LCA can show ecological advantages of certain raw materials, processes or products. This external use of LCA is for most manufacturers more attractive than the internal use.

The external use of LCA has become an instrument in marketing of products made of different materials (e.g. wood versus plastic or aluminium for windows). We may like it or not, LCA enjoys most attractiveness when a comparison between two products or services is made.

Why is LCA a challenge for forestry and forest products industry?

I would like to explain the challenge by discussing three aspects of the LCA-approach:

- Existing studies do not reflect the reality of forest ecosystems and forest industry practice.
- Missing methodology for LCA/LCI in forestry and forest products sector.
- Forests have to be considered as impact category in LCA-studies.

Firstly, most of the existing LCA studies on wood products including paper have been prepared by experts who are not familiar with the forestry or forest products sector. Most often, the studies are prepared for the reason of comparison, for example: packaging systems made from wood/paper, metals, glass or plastics; window frames. Experts in forestry/forest products are generally not very satisfied with the approach and/or result of those studies. But we do know that a LCA-study is only as good as the data base gathered in the Life Cycle Inventory (LCI). The LCI is based on data collected in raw material provision, processing, distribution, and utilisation of products. Forestry and forest products industry have to provide data to ensure that LCI reflects reality.

Why should the forestry and forest products sector refrain from conducting its own LCA-studies? LCA is not only beneficial for the external use, more often and in the short range it is the internal positive effect which pays. Quite often, it also leads to the reduction of costs.

Forestry, as far as I know, has not yet dealt with LCA at all. Their traditional thinking is: We are already environmentally friendly due to the biological production and the wide variety of positive ecological and social functions of forest ecosystems. Furthermore, many foresters may think that the problems of harvesting methods, species selection for man-made forests or pesticide application are not that serious that main emphasis had to be put on ecological thinking.

It is very obvious that we find many data about pesticide application, use of heavy machinery in harvesting, clear cutting, and other negative environmental effects through timber cutting in existing LCA, which are prepared by experts outside the forest sector. However, the positive effects of forestry practice and forests are not mentioned by these experts. Certainly, considering ecosystems such as forests as a wood production facility is difficult with regard to the present methodology of LCA.

In summary, our sector has to provide data for LCI. We are by far not satisfied with existing LCA-studies. LCA for products and processes will become of very high interest and therefore, forestry and forest products industry should by all means use the instrument LCA.

Let me now discuss the second aspect of the challenge beginning with a necessary explanation: Almost everyone in this workshop knows in a general way what LCA means and what it is. Therefore, we as the organisers have invited you as the experts on LCA. But we all know that there is no common methodology or structure of LCA in forestry or in the forest products sector even if we put all our knowledge together.

This exactly was one of the reasons for organising this workshop. I am sure we need more, many more meetings to develop a clear picture of LCA in forestry and forest products.

Let us now have a closer look at the existing LCA-studies. Most studies are incomparable because of different system boundaries, different input/output factors, and different allocation procedures. Thorough inventory which is an integral part of LCA is performed very seldom.

This, of course, is not only a problem for us, it is a problem for everybody dealing with LCA. But as long as there is no common methodology, LCI or LCA-studies will not be comparable.

This problem is the second challenge for forestry and forest products industry. The methodology needs special attention when dealing with renewable materials.

Let me take a few minutes of our time to introduce you to the activities of ISO and the development of Life Cycle Assessment Standards. Within ISO, the former and ongoing activities of SETAC (Society of Environmental Toxicology and Chemistry) has got an official platform. ISO has created the TC 207 with its five subcommittees (SC). The SC 5 „Life Cycle Assessment“ consists of 5 working groups (Figure 1). SC 5 and the working groups started their activities almost two years ago.

<u>ISO TC 207 Environmental Management (June 1993)</u>

SC 1	Environmental Management Systems
SC 2	Environmental Auditing
SC 3	Eco-Labelling
SC 4	Environmental Performance Evaluation
SC 5	Life Cycle Assessment

<u>ISO TC 207 SC 5 Life Cycle Assessment</u>

WG 1:	Life Cycle Assessment - General Principles and Procedures
WG 2+3:	Life Cycle Inventory Analysis
WG 4:	Life Cycle Impact Assessment
WG 5:	Life Cycle Improvement Assessment

Figure 1. ***Structure of ISO TC 207 and ISO TC 207 SC 5.***

ISO TC 207 SC 5 is developing a set of standards for environmental management directed towards LCA (Figure 2). The procedure for the development of an ISO-standard is shown in Figure 3.

ISO/CD 14.040.2	Environmental management - Life cycle assessment - Principles and guidelines (comments and voting until June 1995)
ISO/WD 14.041	Environmental management - Life cycle inventory analysis (likely to become CD in Nov. 1995)
ISO/14042	- Life cycle impact assessment (no WD established yet)
ISO/14043	- Life cycle improvement assessment (no WD established yet)

Figure 2. ISO TC 207 SC 5 proposed standards.

Working Draft	- prepared by WG
↓	- SC 5 decision
Committee Draft	
↓	- Ballot
Draft ISO Standard	
↓	- Ballot (min 2/3 of member countries)
Standard	

Figure 3. Procedure for ISO-Standards on LCA.

The working groups of ISO TC 207 SC 5 has been very active. Up to now, one committee draft (CD) 14.040.2 and one working draft 14.041 have been prepared but not agreed upon.

The definition of the requirements of forestry and forest products sector for the ISO work is the third challenge and one of the aims of this workshop.

The LCA experts see LCA as a systematic tool of assessing the environmental impacts associated with a products or service system (ISO WD 14.040). A LCA-study should comprise

- goal definition and scope
- inventory analysis
- impact assessment
- improvement assessment

I would like to stress two points:

- The methodology for LCA being developed within ISO ignores the specific problems of forestry and forest products industry. Without going into details, the LCI methodology contains some problems for us (Figure 4).
- The definition of system boundaries shall be determined by their importance for the result of the study. The forest activities include positive ecological effects which are often called social aspects. Many LCA experts believe that "social aspects" or "time effects" should not be considered in LCI and LCA. But these aspects are important in forestry. Fore example: Forests as a carbon sink are time-related. Another unsolved area in the methodology is the allocation problem. What is the environmental burden allocated to the main products and the by-products?

  Example: If we employ recycled fibres (waste paper), do we get a "positive environmental load" because the waste paper otherwise would have been burnt or dumped in a land fill? Or does the waste paper (recycled fibre) still carry all the "negative environmental load" from the previous paper? Or is forestry still considered in connection with recycled fibres?

- Cut-off criteria/System boundaries
  i.e. "raw material manufacture",
  natural decomposition of wood
- Input/output factors
  i.e. social aspects - in-/outputs in forestry
  time effects - forests/timber products as a carbon sink
- Allocation procedures
  input/output factor allocation in forestry/timber industry
  i.e. - forest road building - use of it for various reasons
  - use of wooden mill residues for energy generation

Figure 4. Examples for problem areas from the viewpoint of forestry/forest products industry related to LCO according to ISO WG 14.041.

There are many unsolved problems! Therefore, the development of a suitable methodology for LCI/LCA in forestry and forest products industry is a challenge. The sector, especially forestry and forest products scientists, have to develop it. Nobody outside the sector will develop it in a such way as we like to have it.

The third challenge is even more complex. The impact assessment which is a substantial part of a LCA-study is recommended as a three-step procedure (Figure 5).

- Classification
  grouping of input/output factors
  into impact categories
  - general categories
    human health
    ecological impacts
  - specific categories
    i.e. global warming
    acidification
    eutrophication
- Characterization
  analysis and quantification of the
  impact in each of the selected
  categories ("environmental load-
  response-relationships")
- Valuation
  ...determination of significance of
  the results of the impact assessment...

Figure 5. Impact Assessment: three step procedure.

Firstly, the classification, which means that impact categories are defined and the input/output factors are grouped into these categories. Examples for general or specific categories are mentioned in CD 14.040.2 as there are: inputs and outputs with a potential for global warming will be selected and assessed by its impact on global warming. Under characterisation the load-response-relationship is qualified and quantified and afterwards evaluated.

The aspect of a challenge especially for forestry is that:

- Forests are part of the environment, they could be considered as an impact category of its own.
- Forests are a substantial part of the global ecosystem and are negatively influenced not only by foresters planting wrong trees or harvesting in the wrong way. Forests are also negatively influenced by polluted air, acid rain, land use, etc.
- Forest science has analysed the load-response-relationship mentioned above, but for better impact assessment, we have to enlarge this knowledge. In other words: LCA includes questions on environmental impacts on forest ecosystems.

This opens up a wide sector of research, and a real challenge.

LIFE CYCLE ANALYSIS IN FORESTRY

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Abstract

The results of LCA studies depend highly on the methodology used. LCA is a method mainly focused on industrial production. However, a complete LCA study on timber products has to cover the forest part as well. For pointing out the comparative advantages of wood products, it is necessary to include the process of biological production into LCA, to look at stocks and not flows only, to consider the site conditions of raw material production, and to include effects on, for example, land use and landscape.

At the Institute of Economics of the Federal Research Centre for Forestry and Forest Products there is an ongoing project covering different life-cycle stages of wood products. This paper describes the model developed. The challenges of the future in LCA are discussed in the conclusions.

1. Introduction

During the last years Life Cycle Analysis (LCA) has been developed to an instrument for several purposes, especially for:

1. assisting in decision-making for environmental improvement in industrial enterprises (i.e. improvement of products and technical processes),
2. marketing by giving prominence to the environmental improvements or benefits of a product,
3. advising in the process of public decision making.

As Frühwald (1995) already mentioned the results of LCA studies highly depend on the methodology used. In order to gain more comparability of LCA studies as well as to prevent a misuse of this instrument the International Standardization Organization (ISO) has established (under ISO/TC 207/SC 5) working groups, which are developing an international standard on LCA. Although it seems that research in many fields of LCA is still in the beginning, the LCA standard will be passed very soon.

LCA is defined as an instrument to evaluate the environmental burdens associated with a product, a process, or an activity by identifying and quantifying energy and material uses and resultant environmental releases. In accordance with the working groups of ISO, LCA can be divided into four elements:

1. Definition of goal and scope
2. Life Cycle Inventory (LCI)
3. Life Cycle Impact Assessment
4. Evaluation or Life Cycle Improvement Assessment

The definition allows to use LCA for several purposes. Therefore in the initial part of a LCA the purpose and the scope of a study have to be defined clearly and the system boundaries of the study have to be described clearly in order to ensure comparability with studies about other products or processes. The system boundaries in most LCA studies are restricted to the industrial process following raw materials acquisition. Frühwald (1995) mentioned various LCA studies referring to products which are in a substitutional or competitive relationship to wood products. But up to now only few LCAs have regarded wood and wood products (Richter, 1992), and these few ones have concentrated on the wood processing industries and the use of wood products and not regarded the field of forestry and forest production. It is of eminent importance to include raw materials acquisition and resource depletion into LCA. Only by doing this the main advantages of using renewable resources instead of non-renewable, exhausting ones can be demonstrated.

It is generally accepted that in LCA ideally all material and energy inputs should be traced back to their extraction from the environment and all releases should be traced back to the environment. This has to be registered in the Life Cycle Inventory. In reality however, in LCA studies decision rules or cut-off criteria are used to set the system boundaries. Cut-off criteria serve to limit subsequent data handling to those input/output data which can be made available and which are significant to the results. Any omission of a phase of the life cycle needs to be clearly stated and to be justified. A very convincing argument for omitting the phase or an element of raw materials acquisition or production is a lack in adequate data and a lack of adequate methods enabling to include the biological production process into the framework of LCA.

Yet LCA is a method mainly focused on industrial production. A complete LCA study on timber products has to include a modul, which covers the forest part. In our Institute for Economics we try to develop such a modul for German Forestry. But before explaining the structure of this LCA modul some methodological aspects shall be taken up, which are significant for pointing out the comparative advantages of wood products. These are:

1. The necessity to include the process of biological production into LCA,
2. The necessity to look at stocks and not on flows only,

3. The necessity to consider site conditions of raw materials production,
4. The necessity to include effects on land use, landscape etc..

These aspects are not considered in the drafts of the ISO working groups for Lice Cycle Assessment, yet (Frühwald, 1995 Appendix).

2. *Methodological aspects*

2.1. Necessity to include the process of biological production into LCA

More sustainability of economic and social development is a high ranking goal of international an national environmental policy. It is one of the leading ideas of the Agenda 21 which has been agreed at the UNCED conference in Rio de Janeiro, June 1992. The use of renewable resources produced on the basis of a sustainable management will be a decisive element for realizing that ideas of sustainable development. Therefore the main advantage of using renewable resources instead of non-renewable ones, the biological production of the raw materials, should be covered by LCA which claims for analyzing the whole life cycle of a product from cradle to grave. But the main ideas of LCA are directed to the registration of technical processes, yet. It is argued that the biological production process itself is of minor importance for the production and use of the bulk of industrial products, that it is too much specific and that the relevant effects are too diverse for integrating them systematically into LCA. But it is general consensus that all relevant environmental burdens have to be recorded in the LCI; burdens, like emissions to water, atmosphere and soil. Before starting with LCI it has to be decided which emissions will have to be registered. To be able to characterize a substance as a burden, knowledge is needed about the relevant impacts. This, in principle, is the task of the impact assessment. Only a serious impact assessment can characterize a substance as an environmental burden. If the emission of a substance (like CO_2) is interpreted as a burden, consequently a reduction of this environmental burden by fixing this substance in the biological growth process should be stated in the inventory and should be interpreted as a benefit. In Germany the word ecobalancing is often used in the framework of LCA. This term balancing expresses very well a main idea of what should be done in LCA; a balancing of all ecological effects related to the life cycle of a product. If the relationship between a substance and its environmental damage is known it should be possible to show the benefits of fixing this substance in the biological growth process, too. In comparison with fossil raw materials the use of renewable resources for instance releases CO_2, which has been fixed during the preceding biological growth process, while the use of fossil raw materials releases CO_2, which has been fixed millions of years ago.

2.2. *Necessity to look at stocks and not on flows only*

LCI concentrates on flows. This seems to be consensus in the corresponding ISO working groups. It has to register (in a modular manner):

- all inputs from outside the system boundaries, like energy, raw materials, ancillary materials, semi-finished products etc.,
- all outputs towards outside the system boundaries, like products (including services, energy etc.), emissions, depositions, effluents.

These flows of inputs and outputs have to be added up covering the whole time period of the life cycle from cradle to grave. These aggregated flows then are related to units of the product, respectively to functional units.

Applying this principle the different steps of the life cycle, which in reality follow one to another, are analyzed simultaneously. This procedure is common in other analyses of forest production, for instance in the national accounting system, too; but for LCA it is insufficient. It does not allow to consider changes in the growing stock and sink effects. Especially sink effects, those of the forests as a carbon sink, are of great importance for environment. This carbon sink effect can temporarily be extended over that period in which the use of wood products postpones the natural decomposition. Considering the importance of these effects in the international discussion of global warming, it should be take care of registering such stock effects in LCA. If it is not possible to complete the flow-accounting of LCA by a stock-accounting, specific stock effects should be considered by additional registration. In the case of the CO_2 effects of forest production and wood products there is a lot of material available (Wegener, 1994; Burschel, 1994).

2.3. *Necessity to consider site conditions of raw materials production*

To concentrate on the flows of physical elements in LCA - which seems to be appropriate for the assessment of the environmental quality of industrial production processes - is inappropriate when judging the environmental quality of raw materials acquisition. The fundamental difference between renewable resources (like wood) and non-renewable ones has been already mentioned and it was claimed to include the biological production process itself into LCA. But there are further fundamental differences between raw materials acquisition and industrial production.

The impacts of industrial production processes on the environment are mainly based on process-engineering and mostly independent from their specific location. But the effects of raw material acquisition are often extremely site specific. The productivity of raw materials production in agriculture as well as in forestry is very close related to climate, soil fertility etc.. The productivity of non-renewable resources acquisition depends on site conditions, like richness of the deposit etc. as well. Specific site conditions often require specific technical equipment and specific process-engineering. According to this site dependence of raw materials production, the geographical validity of LCA studies about raw materials acquisition would be quite limited. To include this first link of the chain from cradle to grave is a principal handicap of LCA studies. In principle for all raw materials used in the production process a modul is needed which is representative for the process of raw materials acquisition or production at the specific sites, where the raw materials come from. This would require a system, which enables to follow the specific flows of the raw materials from their origin to the following steps of the production process during the whole life cycle of a product. This seems to be absolutely impractical yet. If it is impractical to follow the flow of raw materials, and to assess the site specificity, the process of raw materials production has to be standardized. Foresters and forest-scientists often emphasize that the site related nature of forestry is a fundamental law. It is difficult to convince them that looking at a standardized process of forest production is of any use at all. But integrating forest production into LCA, needs the process to be standardized at least for geographical units, which can be handled in the following moduls of the chain from cradle to grave.

2.4. Necessity to include effects on land use, landscape etc.

Other important points not considered yet in LCA and consequently not considered in the proposals of the ISO working groups are the various effects of raw materials production, respectively acquisition on land use, landscape, biodiversity etc. Especially forest production is claiming for beneficial effects to the environment, like protective effects on soil, atmosphere water etc.. In spite of these mostly beneficial effects of forest production, raw material acquisition often causes severe interference with the environment. Striking examples can be shown for mining: destruction of natural groundwater reservoirs, destruction of the landscape etc.

A standard argument for cutting-off these effects in LCA is a lack of methods for measuring such effects. Further it is argued that LCA does not claim for complete registration of all environmental relevant effects. Often it is pointed to instruments like the environmental impact assessment, where these effects are enumerated and valued comprehensively. But such an environmental impact assessment for raw material acquisition is only done in countries, where this procedure is prescripted. In order to assess the environmental quality of goods and services (and this is, what LCA is aiming at) all relevant environmental effects should be listed without respecting the place of origin and they should be valued adequately.

The lack of empirical data describing the environmental benefits of forest production is often deplored (Bergen, 1991). The requirement of this kind of data completing the picture of LCA should give additional impetus for forest-research.

3. *LCA of forest production in Hamburg*

At the Institute for Economics of the Federal Research Centre for Forestry and Forest Products a project "Analysis and assessment of forest production as a basis for further Life-Cycle-Analyses in the field of forest industry" is in progress. This project is an element of a pilot project covering different life-cycle stages of wood products: The Institute for Wood Research at the University of Munich is analyzing in a modul "sawmill" the production process of different types of sawnwood; at the Chair for Wood Technology at the University of Hamburg two products and production processes are analyzed, a modul "window manufacturing" and a modul "roof framework".

The modul "forest production" has to supply basic data about forest production in Germany in order to integrate the production process of wood into the already mentioned following moduls. This is the main task this project is aiming at. Besides that the project is directed towards two other goals: First, to the development and examination of a methodology which enables the inclusion of forest production into LCA and second, to the assessment of forest production.

The structure of the study follows the standard model of LCA mentioned in Chapter I. In Figure 1 the horizontal structure of the modul "forest production" as the first link in the chain of a product's life cycle is presented. The figure shows the different input- and output-flows towards and from the modul "forest production". The inputs and outputs can be subdivided into two groups: Inputs from inside and from outside the system as well as outputs towards outside and towards inside the system. Although forest production is the first link in the chain of wood products there is one input from a premodul: seedlings from tree nurseries outside the forests. Inputs from outside the systems are removals from the environment, like CO_2 and water as well as primary energy (solar energy, fossil fuels) and ancillary materials, like lime and pesticides. Emissions into the air, effluents, depositions and immaterial services are outputs towards outside the system. The single outputs to the following moduls covering production processes in forest industry is wood as material, energy and CO_2 carrier. The (functional) unit is defined as a ton of absolute dry sawlog respectively industrial wood of the main tree species in Germany: Oak (*Quercus petrea*), Beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and Pine (*Pinus sylvestris*). All inputs and outputs are related to this functional unit.
The vertical analysis of the modul "forest production" is shown in Figure 2. The modul is subdivided into eleven submoduls which are covering the main processes of forest production in Germany.

At the left side the subsequent steps of stand management from stand establishment to final cutting are shown in a chronological order. The submoduls

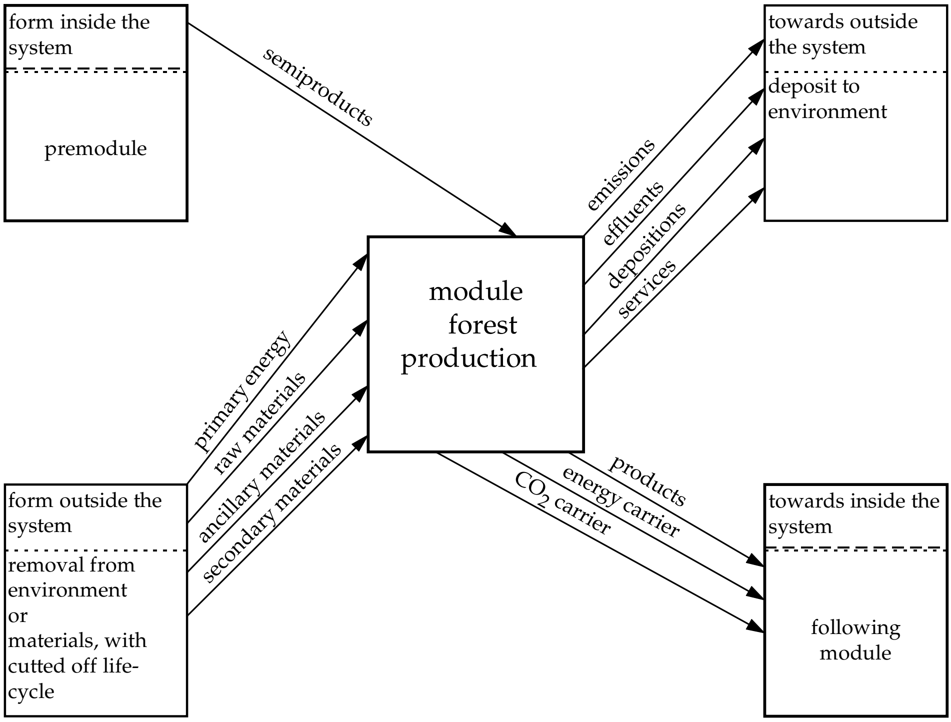

Figure 1. Horizontal analysis of forest production.

at the right side are more or less independent of a stand's age. The model aims at representing average conditions for forest production in Germany. The biological system "forest" is regarded as part of the modul. In a first step, only few general data of the biological process are collected. Data collection is concentrated on those data which are valid for the biological system independent from any specific site conditions. These are at the input side CO_2, water and solar energy and - if mean data are available - some gaseous emissions.

At the output side these are O_2, energy and carbon stored in wood.

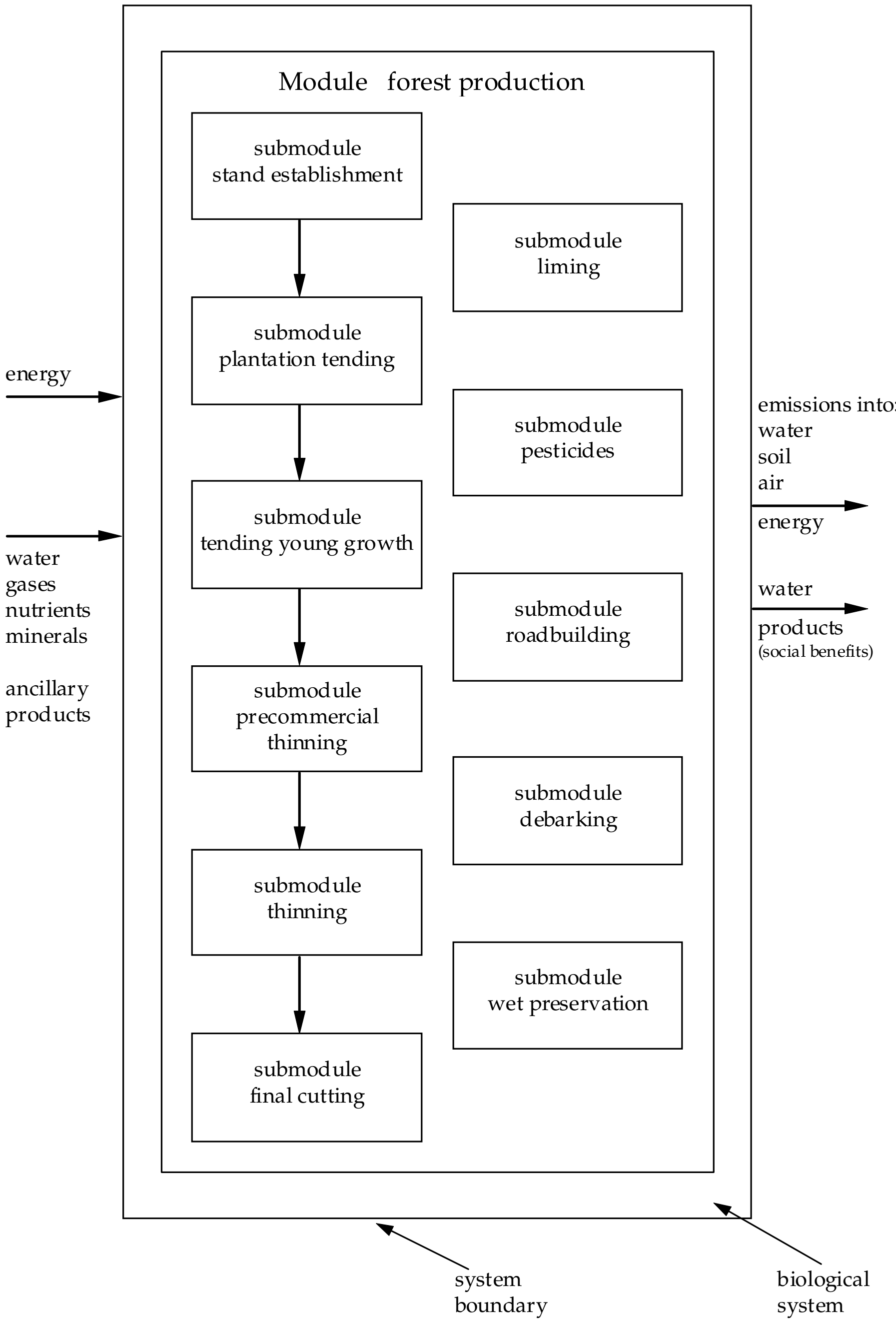

Figure 2. Vertical analysis of model "forest production".

4. *Conclusions*

LCA is an instrument which is used and can be used for different goals and in different manners. To avoid misuse, there are activities on national and international level to standardize LCA. Arno Frühwald informed about this process (Frühwald, 1995).

Those who are involved into this decision making process of standardization have to be convinced that it is important to take care of the specific problems of raw materials production and acquisition in LCA. Forest research has to demonstrate how this could be done. The increasing environmental awareness has raised discussion about forest management practices. Efforts for getting back market credibility of wood products, which has been eroded by the discussion about tropical rainforests destruction and adverse environmental impacts of some forest management practices in a lot of countries all over the world, have raised worldwide activities in order to define environmentally appropriate forest management. Within this context standards for forest management are developed which aim at a scheme of certification of "well managed" forests (Upton, 1995). So far, LCA should be distinguished from such certification schemes because the assessment criteria of certification are not consistent with those of LCA. The requirements of what has to be registered in a modul "forest production" as a first link of the chain from cradle to grave are determined by the claims and possibilities of the following links of the chain. After LCA had been standardized it might be one task for the future to harmonize the criteria catalogues of life cycle assessment and certification.

The development of LCA necessarily has to be continued in a quite pragmatic manner as it is done in ISO working groups. Because of great difficulties handling the LCA components "assessment" and "improve assessment", lots of efforts are concentrating on LCI.

And indeed, there is an enormous demand for collecting data, relevant to the environment. But only by aggregating the various inputs and outputs the possibility exists to assess the environmental relevance of a product's life cycle. Unfortunately, there is a resistance against economic valuation in the process of data aggregation. This seems to be inappropriate because economic aggregation procedures, like shadow pricing or avoiding costs might be helpful to condense the abundance of data to reasonable results.

Another task for the future might be the coordination of LCA with environmental accounting like UGR (Statistisches Bundesamt, 1993). Currently in LCA only cut-off criteria allow to handle phenomena like joint-production or by-products. This contents the risk that the bottom up process of LCA becomes inconsistent. The top down approaches of environmental accounting systems may be a tool to minimize those inconsistencies.

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LIFE CYCLE ANALYSIS IN THE CONTEXT OF FORESTRY ECO-LABELLING

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Abstract

This paper gives an overview on the the main challenges facing LCA for wood and paper products. Problems of identification of effects and marketplace creditability for forestry eco-labelling are described, and in the end, the harmonisation of eco-labelling programmes is discussed also.

Introduction

There is increasing interest in life cycle eco-labelling of many forest products. Such labels cover standards not only for forest management, but also for pulping, packaging, manufacture, transport, use and disposal. Examples include the European Commission regulations which establish criteria for the eco-labelling of toilet paper [Reg: 94/924/EC] and kitchen rolls [Reg: 94/925/EC].

Forest certification is often presented in a way which makes it synonymous with eco-labelling. This is confusing, as there is an important difference. *Forest certification* is more correctly defined as a *single issue eco-label* - wood and paper products are labelled according to whether the forests they originate from are well managed. Forest certification allows the use of an eco-label which only considers the production of particular raw materials - virgin fibre for paper products and timber for products using wood.

More usually, *eco-labelling*[1] *is multiple issue* and adopts a cradle to grave analytical framework [life cycle analysis or LCA]. The starting point for a life cycle analysis is the correct identification and prioritisation of environmental effects throughout a product's "life cycle". Typically, a matrix is prepared which ranks the relative importance of environmental effects according to each phase of the product cycle. Criteria which set standards for each effect identified as significant are then developed. An acceptable identification of effects is one of the main challenges facing LCA for wood and paper products. A credible forest certification programme could be of assistance in facilitating this work.

[1] In this paper the term "eco-labelling" refers to multiple issue programmes requiring LCA; and the term "forest certification" refers to a single issue programme covering forest management.

A forest certification programme could fulfil part of the requirements for an eco-label provided mutual recognition between the two programmes existed. For example, pulpwood originating from a forest certified under a Swiss wood certification programme could form part of the EU eco-label for toilet paper. Current eco-labelling initiatives should consider ways in which existing and credible forest certification programmes can be accepted. Such recognition would facilitate the development of eco-labels and reduce the cost of their application.

For forest certification initiatives to be successfully used within eco-label programmes market place credibility of the forest certification programme - as well as other aspects of the eco-label - is essential. Unless the eco-label is credible in the market place industry will not be able to obtain competitive advantage from participating and is unlikely to do so. Credibility in the market is bound up with the issue of the criteria which set the standard for identified effects; and which need to satisfy stakeholder requirements.

Given public concern over forest management world-wide it is likely that the credibility of an eco-label for wood and paper products will be directly influenced by public acceptability of the criteria used to define management of the forests from where raw materials are derived.

Identification of effects

Assessing and valuing many different types of environmental effects to determine the net environmental impact of a product throughout its entire life, and then comparing these across products, is very difficult and time consuming. At present, there is also little experience in doing so.

Thus, in practice, in assessing the environmental impact of a wood or paper product, a few specific aspects are focused upon rather than the entire life cycle. These aspects then become the basis for the second stage, the development of a standard, and the criteria, that the product must meet to obtain the label.

In LCA a matrix is often drawn up to illustrate the priority environmental impacts of a product's life cycle. Figure 1 illustrates such a matrix showing a possible framework for a paper product. The product cycle is divided into its main phases which are further sub-divided into the key activities of each phase. Whilst the overall standard for the eco-label can include direct reference to the main phases which should be included, key activities may well be specific to each applicant and can only be indirectly referred to. However, the eco-label standard should include guidelines which ensure an appropriate selection of key activities. Where third party inspection is required, a further assurance that key activities are correctly selected would be achieved through the accreditation conditions for inspection bodies.

As with the main phases of a product's life cycle the potential environmental effects of each phase are arranged under main effects, which are common to all

LCAs for the particular eco-label, and which are subdivided to ensure that locally specific impacts are adequately covered.

At present, there is significant variation between the LCA frameworks of the different eco-labelling programmes which cover wood and paper products. For example, many recycled paper programmes, although allowing for a proportion of virgin fibre, do not include forestry as a main phase of the product cycle; whereas others do - two schemes Germany's Blue Angel and the EU's Eco-label are discussed in more detail below. To some extent, such variation reflects the different environmental priorities of local, regional and national communities. However at an international level such variation can also work as a barrier to trade, which in particular, might restrict the trading opportunities of poorer countries. Differences in the LCA framework between eco-labels for similar products also raise the danger that competition between eco-labels will be on the basis of standards and scope rather than the cost and effectiveness of implementation and inspection.

Priority environmental impacts that are identified through the LCA require a standard against which performance can be measured. This is the most important aspect of a labelling programme and often the most controversial - especially for parts of the product cycle which require significant amounts of professional judgement, like forestry. Often minimum levels of performance [threshold values] are defined in the eco-label standard itself for particular activities that are assumed as being common to all applicants - for example a numerical value for emissions, energy use, or product content.

Developing threshold values for forestry is rather more difficult than for other aspects of a product's life cycle due to the site-specific nature of the environmental effects of forest management. Manufacturing processes are usually easier to control and define. There is also more experience in environmental assessment of industry practices than forestry. The example of the EU eco-label for toilet paper and kitchen rolls cited below, illustrates the difficulty that forestry presents to LCA.

Once it has been decided that forestry should be included as part of the LCA there are two options in developing appropriate criteria: either the eco-label can include reference to an existing and credible forest certification programme; or it can propose development of its own criteria. The example of the EU eco-label takes neither of these two routes; it will be interesting to see how this aspect of the eco-label is covered during the assessment of applications. The EU eco-label makes a definition of forest management but fails to specify how it should be interpreted at a site level except for the production of a declaration of conformity by the applicant. Given the variability between forests, even within relatively homogenous geographic areas, such an approach makes this aspect of the eco-label very difficult to implement. It is perhaps fortunate that the forest management part of the EU eco-label does not require the production of inspection results!

POTENTIAL IMPACTS ON:

ACTIVITIES IN DISPOSABLE PAPER PRODUCT LIFE CYCLE	Natural Resources					Terrestrial Ecology					Atmospheric Effects			Disturbance					Human Health		
	energy use	water resources	landfills	erosion and soil quality	loss of traditional land uses	loss of habitats	reduction of ecological diversity	reduction of genetic diversity	introduction of persistent pollutants	lowering of water quality	regional climate change	global warming	acid rain	noise	local air pollution	visual intrusion	litter	transport and traffic	exposure to dangerous substances	contamination of human food chain	risks of spills and accidents
forest management																					
silviculture		⊗					⊗	⊗		⊗	⊗				⊗	⊗					
harvesting		⊗		⊗		⊗	⊗	⊗													
public participation					⊗				⊗	⊗	⊗	⊗			⊗	⊗		⊗			
pulp production																					
pulping	⊗	⊗							⊗	⊗											
use of virgin pulp instead of recycled fibre	⊗	⊗																⊗			
chemical treatment of pulp			⊗						⊗	⊗							⊗			⊗	
production of recycled fibre										⊗					⊗						⊗
production and use of chlorine									⊗						⊗					⊗	⊗
disposal of solid waste			⊗																		
paper production																					
bleaching with chlorine	⊗	⊗								⊗		⊗	⊗	⊗	⊗						
use of conditioners and dyes									⊗											⊗	
disposal of acid waste			⊗						⊗												⊗
disposal																					
packaging and distribution																		⊗			
use of product						⊗					⊗								⊗		
disposal																					
disposal to landfill		⊗	⊗							⊗		⊗								⊗	
disposal in sewage			⊗							⊗											
disposal by incineration			⊗												⊗						

Figure 1. Identification of effects - possible scenario for disposable paper.

There are currently few examples of forest certification programmes which have sufficient market acceptability for their inclusion as part of an eco-label. The Forest Stewardship Council[2] [FSC] is currently accrediting certification bodies to issue certificates for forests which are managed according to ten Principles and Criteria. In addition, accreditation to environmental management systems [EMS] standards is now starting in several countries - the UK has been the first to include forestry as part of the awarded scope of accreditation for BS 7750.

There has, however, been considerable debate regarding the use of established Environmental Management Systems [EMS] standards in forest certification. Antagonists argue correctly that EMS standards such as BS 7750 do not prescribe the level of performance by which a Forest Management Unit [FMU] will be assessed. BS 7750 does not set absolute requirements for environmental performance beyond compliance with applicable legislation and regulations, and a commitment to continuous improvement. Thus two forest management units having different levels of environmental and social performance may both comply with the requirements of the standard.

Protagonists argue that EMS standards, by focusing on processes, better reflect the reality of forest variability; the various environmental and social priorities of different forests; and that the commitment to continuous change embodied in the EMS standard assures improved environmental and social performance.

The Canadian Standards Association [CSA] is developing a standard for forest management which aims to incorporate the merits of a systems approach to forestry [as defined by an EMS standard] and which sets an acceptable level of performance through principles and criteria. The Canadian standard brings these together in what is defined as the "Sustainable Forest Management System", the key question being whether or not a defined area of forest land is being managed according to an SFM system with associated principles and criteria that are acceptable to stakeholders. The CSA initiative is also designed so that the SFM system specification is compatible with the SFM principles being developed in other fora. These include: the Helsinki Process, the Montreal Process, the International Tropical Timber Organisation [ITTO] and the United Nations Commission on Sustainable Development.

Even when appropriate principles and criteria for forest management have been selected by or defined in the eco-label, the site specific nature of forestry operations means that detailed internal standards are required for each management unit. Often a matrix is drawn up to identify and prioritise site specific environmental effects. Figure 2 illustrates an example for plantation forestry; and Figure 3 illustrates a framework - used in the New Zealand code of forestry practice - which attempts to also identify short and long term effects.

[2] The Forest Stewardship Council [FSC] is based in Mexico and was formally created in 1993 with the objective of developing an international certification programme for "well managed forests". The FSC have produced 10 Principles and Criteria to define forest management.

ACTIVITIES IN PLANTATION FARMING	soil and water quality and quantity	loss of ecological and genetic biodiversity		loss of indigenous or cust landuse rights	global warming	human health
conversion of natural forest	✪	✪	✪	✪	✪	
site preparation	✪	⊗	✪	⊗	⊗	✪
species selection and breeding		✪				
tending		⊗	✪			⊗
harvesting	✪	⊗	✪		✪	⊗

POTENTIAL IMPACTS ON: (column heading)

very likely	✪
possible	⊗

Figure 2. Identification of effects - possible scenario for plantation forestry.

Important environmental values

Forest operations	Recreation	Community	Wildlife	Aquatic life	Water quality	Soil erosion	Forest health
Planting							
Fertilizing							
Weed control							
Mechanical prep							
Burning							
Waste thinning							
Pest/animal control							
Disease control							
Access roading							
Access tracking							
Firebreaking							
Landing construction							
Steam crossing							
Felling							
Processing							
Extraction							
Road maintenance							
Transport							
etc...							

Matrix scoring system

Degree of impact	Period of impact	Significance
Major	Long term	+ + +, - - -
Major	Short term	+ +, - -
Minor	Long term	+ + , - -
Minor	Short term	+, -

Figure 3. Environmental impact assessment of forest operations - a matrix system to identify potential environmental impacts.

Once priority environmental effects have been identified specific criteria should be drawn up which ensure compliance with the external standard. In the context of an EMS these are expressed as objectives and targets.

Two examples - that of the Blue Angel and that of the EU eco-label - are given to illustrate how forestry is considered in current in eco-labelling initiatives. Eco-labelling programmes for wood and paper products either exclude forestry impacts completely; or include criteria generally considered as inadequate by those involved in forest conservation.

An example of the former is *Germany's Blue Angel environmental label programme* which includes several sets of criteria for paper products. These criteria confine their coverage of forestry by simply setting minimum thresholds for wastepaper content. For example RAL-UZ 14 for Recycled Paper and RAL-UZ 56 for recycled cardboard both specify that products marked with the label must be made of 100% scrap paper [a tolerance of 5% is allowed], i.e., effectively excluding the use of virgin fibre from forests - however well they are managed. RAL-UZ 35 for Wall-Papers and Ingrain Wall Covering Made from Recycled Paper specifies that wall-papers should consist of 60% scrap paper; and ingrain wall covering 80% scrap paper. No criteria are specified for virgin wood fibre which is allowed under RAL-UZ 35. It is clear that the priority environmental effect which the Blue Angel eco-label is attempting to deal with is waste reduction rather than potential negative impacts of forest management. However, it is interesting to note that within the German publishing industry there are now moves to focus more on forest management and rather less on waste disposal for reasons of paper quality.

The *EU ecolabel criteria for toilet rolls and kitchen towels* has identified and includes forest management as an environmental effect. They allow for the use of recycled fibre and fibre from forests where environmentally-appropriate management is practised. Acceptable forest management is defined as that adopted by the Ministerial Conference on the Protection of Forest in Europe [Helsinki, June 1993] - resolution H1:

> "... the stewardship and use of forests and forest land in a way, and at a rate, that maintains their bio-diversity, productivity, regeneration capacity, vitality and this potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels and that does not cause damage to other ecosystems."

For those states that have not adopted the Helsinki resolution, forestry management must be in accordance with the principles decided at the UNCED Conference in Rio de Janeiro in June 1992 ["non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests"]. These definitions permit the inclusion of virgin fibre in toilet paper and kitchen rolls covered by the criteria.

However, there are a number of problems with the definition of forest management used in the EU ecolabel. Firstly, environmental groups have not accepted the Helsinki Resolution on forestry management as it is ambiguous in its interpretation and lacks independent mechanisms for verification. Secondly, despite allowing virgin wood fibre to be included, the definition of renewable resources for both toilet paper and kitchen rolls excludes as relevant wood fibre deriving from:

- forest thinnings to remove sick or damaged trees or to make space for remaining trees
- windfalls and trees broken under weight of snow
- wood waste [saw dust, trimmings and bark] from saw mills

Essentially, therefore, only wood from final cut operations is included. With regard to toilet paper and kitchen rolls this represents a small proportion of the virgin wood fibre used and prejudices against organisations establishing plantations entirely for pulp.

From the perspective of environmental groups, the EU eco-label provides not only a vague definition of forest management criteria and excludes nearly all wood from the definition of renewable resource consumption; it also fails to allow explicitly for independent inspection of forest management activities.

For the analysis of chemicals and emissions the criteria require testing by laboratories holding EN 45001 accreditation or equivalent; or, alternatively, institutions registered to ISO 9001 or ISO 9002. However, for forest management an applicant only has to provide an unverified declaration that pulp has been sourced from managed forests in accordance with the criteria definitions.

This is in marked contrast to the rather more specific criteria, accreditation rules and assessment guidelines within the forest certification programmes now being formulated by the FSC and the CSA - both cited above. Under such circumstances, it seems unlikely that use of the EU eco-label will have market place credibility for forest management. However, since the criteria were published in the Official Journal on 14 November 1994, 8 companies in the UK have now requested application form. There are probably more requests in other EU member states. It will be interesting to see how these applicants address the forest management requirements of the eco-label; and the extent to which the EU eco-label will be used to complement an established forest certification programme - such as the FSC.

Within this context, it is significant that the EU eco-label definition of forest management also states: "At the end of a three-year period this Decision will be revised in the light of developments concerning operational guidelines and policies for forest management elaborated in international fora".

Marketplace credibility

Application for both single- and multiple-issue eco-labels is usually voluntary. Such labels aim to enhance the marketing appeal of goods by highlighting their environmentally-friendly characteristics. Both eco-labels and forest certification are economic market-based instruments which aim to raise awareness and provide incentives for both producers and consumers towards improved environmental practice.
Industry may perceive commercial advantage where:

- there is a willingness amongst consumers to pay the extra costs associated with the instrument. This usually takes the form of higher prices, which may be achieved where additional environmental aspects are recognised as enhancing product quality; or
- any associated increase in cost associated with the instrument is offset against other commercial gains. In environmental labelling these could include: [1] medium-term gains in efficiency and productivity; [2] protection of market share and increased marketing opportunities through product differentiation; [3] reduction of environmental risk, resulting in better access to financial markets for loans, rights issues, insurance, etc.; [4] better stock control; and [5] improved image in "green" conscious markets and with employees.

The overriding aim of eco-labelling programmes is to distinguish certain products as having significantly less adverse environmental impact than others in its product category. Eco-labelling can only be effective as a marketing tool to increase sales or to improve the product's or the company's image if accepted by consumers. This depends on increased consumer awareness that some products are better or worse for the environment than others. Eco-labelling programmes must therefore purposefully differentiate between products because only in this way can they identify the environmentally "best" products in a product category.

It follows that an eco-labelling programme will only achieve its marketplace objectives where the label's environmental claims are credible with consumers. A recent WWF report "Truth or Trickery"[3] published the results of three years work on environmental claims and labels. Altogether, 626 companies were researched. Thirty-seven per cent were interested in providing some reassurance to customers as to the environmental acceptability of their products. From these companies a sample of 80 was selected for further investigation to check the quality of their claims. Only three companies were able to make a serious attempt to justify their claims and none could be considered to have answered fully the questions raised regarding their sources. In the light of continued research and a lack of support from trade organisations, in November 1993, WWF sent a direct mailshot to 1153 UK wood product dealers. The letter alerted companies to the issues surrounding inaccurate labelling, the use of the UK

[3] "Truth or Trickery: Timber Labelling Past and Future", WWF [UK], 1994.

Advertising Standards Authority [ASA] to control such claims, and the consideration being given by WWF to the use of legislation such as the Trade Descriptions Act.

WWF's labelling campaign included referrals to the ASA - a watchdog part of whose brief is to ensure that advertisements are "legal, decent, honest and truthful". On 17 February 1993, the ASA upheld a complaint against NHG Timber Limited who had advertised "environmentally acceptable redwood" produced from "sustainable forests". On 16 June 1993 the ASA upheld a complaint against the Malaysian Timber Industry Board who had advertised that their timber was "from one of the world's best conserved forests". Then on 16 February 1994, the ASA upheld a complaint against Magnet Trade, one of the UK's largest suppliers of doors, windows, kitchens and bedrooms. Magnet were claiming that "where hardwood is used, it has to come from a renewable source". Since then Magnet have joined the 1995 Group of companies - see below.

The basis for WWF's anti-labelling campaign is the assertion that existing claims provide misleading information to consumers. WWF feels that many claims create the false impression that all is well with the product in question and an ingenious choice of words can easily pull the wool over the eyes of the trusting customer. To the uninitiated, for instance, the statement "from managed forests" appears to be good recommendation of a product's environmental integrity, yet means virtually nothing.

WWF's position is that, in order to provide adequate market place assurances to consumers, all labelling initiatives must be accompanied by independent monitoring, undertaken in a form acceptable to stakeholders. WWF supports the FSC as being the only up and running forest certification programme which provides such assurance.

As part of its forest conservation programme, WWF established the "1995 Group" in 1991. This is a partnership between WWF [UK] and British companies committed to phasing out wood and paper products from unsustainably managed forests. The Group now has 47 members who account for 10% of the UK market for wood and paper products. As the UK imports 90% of its wood and paper requirements the activities of this Group will inevitably have an international impact. It is significant that the ten largest Group members are almost all mainstream retailers - i.e., are working in direct contact with the consumer. Although the 1995 Group is an extremely diverse collection of companies they are united in their desire to procure all their wood and paper products from well managed sources by the end of 1995. As far as member companies are concerned, "well managed" means those forests which have been independently certified as meeting the level of environmental performance required by the FSC.

Members of the 1995 Group are committed to the FSC as the only currently credible independent certification and labelling system. They are also committed to phasing out purchases of wood and paper products which do not come from well managed forests as verified by independent certifiers accredited by the FSC. Significantly, members of the 1995 Group will be allowed to use the FSC logo as authorised; but other labels denoting well managed forests will not be used.

Harmonisation and mutual recognition

Many of the problems of market credibility and identification of effects will be overcome with time. Indeed there is already a degree of convergence between the various international and national initiatives aimed at setting an environmental standard for forest management; and in setting up certification programmes. This process can be expected to continue as the needs of trade and practical assessment narrow the range of realistic options available. In addition, use of eco-labels in the market place will decide which are successful.

These trends will assist in a harmonisation of eco-labelling programmes for wood and paper products. Eventually a single international standard under ISO [International Organization for Standardization] may become acceptable.

Whilst harmonization can be envisaged for specific products or product groups, this will almost certainly be in terms of defining standards. It is likely that certification and labelling would take place at a national level. For example, the international standard for quality management systems ISO 9000 has international recognition; but certification to the standard is undertaken by certification bodies accredited by national government accreditation bodies.

However, because of the need for taking into account differing national characteristics of the markets and of the environmental concerns, development of internationally harmonised standards may lead to an overall lowering of standards. This is a concern that is often expressed by national stakeholder groups - witness the dilution of national EMS standards currently taking place in the negotiations to create an international ISO EMS standard [ISO 14000].

Another approach to harmonization of eco-labels could be mutual recognition of forest certification labels by eco-labelling programmes for wood and paper products. Eco-labels could automatically cover forest management where it can be demonstrated that raw materials originate from a forest certified by a recognised certification programme.

One difficulty with attempts at harmonisation and mutual recognition between eco-labels is that the criteria between eco-labelling programmes must be similar. The eco-label should be awarded to products with higher than normal environmental attributes among similar products. Since this is a relative measure, the criteria would have to take into account the particular circumstances within various national markets, which may differ according to the environmental priorities of countries.

Probably the best way of ensuring the success of an eco-label and in reducing its impact on international trade is to ensure transparency during its development and operation. This approach requires accountability to the public and the involvement of all stakeholders in the process of setting standards.

HANDLING OF THE CARBON BALANCE OF FORESTS IN LCA

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Abstract

When biotic materials are included in a LCA, the question raises where to draw the border between the nature and the technosphere? This paper concentrates on the system boundary problem with wood formation and degradation of harvesting wastes. Only the carbon balance is considered.

The first part presents some basic principles related to forest ecosystems. Some approaches for quantification of the carbon cycle in LCA are compared and discussed in the second part, and conclusions are drawn based on the presented information.

1. Introduction

Environmental Life Cycle Assessment (LCA) deals with the environmental impacts of a product in its entire life cycle. It summarises all environmental effects to fulfil a certain function. A life cycle consists of all processes related to the functioning of a product: from the extraction of raw materials through the production and use of the product, to the reuse and disposal of all final waste, including the discarded product itself (Berg, 1995).

When the generation of that function needs biogenic materials, it is discussible where to draw the border between the technosphere and nature. Especially when looking at the beginning and at the end of a life cycle of biogenic material (Linfors, 1994). This paper concentrates on the system boundary problem of wood biomass formation and degradation of harvesting wastes. The discussion has to do with the exclusion or inclusion of natural processes in the life cycle of a product. And if included how should the inventory look like: which in- and outflows need to be considered and how can they be quantified? This paper only looks at the following part of the carbon cycle:

- forest growth implies fixation of atmospheric CO_2;
- harvesting produces litter (foliage, branches, roots) that will decay and emit carbon.

In the first part, a literature survey on the influence of forestry on the carbon cycle is presented. In the second part, some approaches for quantification of the carbon cycle in LCA are compared and discussed. In the last part, conclusions are drawn based on the presented information.

2. *Influence of forestry on the carbon cycle*

It is necessary to have a good understanding of the main principles of forestation before trying to answer the problem mentioned in the introduction: how to handle the carbon flow within LCA? Some basic principles related to forest ecosystems are:

- Vegetation withdraw carbon dioxide from the atmosphere through the process of photosynthesis. Carbon dioxide is returned to the atmosphere by autotroph respiration of vegetation and decay (heterotroph respiration) of organic matter in soils and litter. In the absence of significant human activity, the flux of CO_2 from the atmosphere to the terrestrial biosphere, is balanced by respiratory fluxes (IPCC, 1994).
- To understand and quantify the role of forest ecosystems in the carbon cycle, it is necessary to quantify both the net annual carbon fluxes (Mg C $ha^{-1}yr^{-1}$) and the total carbon content (Mg C ha^{-1}) of representative forest ecosystems, thereby including the carbon fluxes and stocks in the soil (Nabuurs, 1993).
- Only **afforestation** can sequester and store additional atmospheric carbon. Afforestation is the planting of tree saplings and thus the establishment of forest on land that was previously not used as forest. The new forest will age and arrive at a balance where net carbon exchange with the atmosphere equals zero and the total carbon content stays constant.
- The wood can be harvested and used for products. Then the litter (and its carbon content) will be stored in the ground as humus. In time carbon will be released: due to product decomposition at the end of the products' life cycle and due to decomposition of the litter and humus.
- Due to **reforestation** it is possible to install a balance between a forest and the products that can be made out of that forest. The net annual carbon flux is zero and the maximum amount of carbon is stored. Reforestation is the establishment of a forest on a site on which the full-grown stand was cut or on a site which was covered with forest in the near past.

Figure 1 (Nabuurs, 1993) illustrates the above theses; it shows the influence of afforestation and reforestation on the carbon stock and carbon flux for a poplar plantation in time.

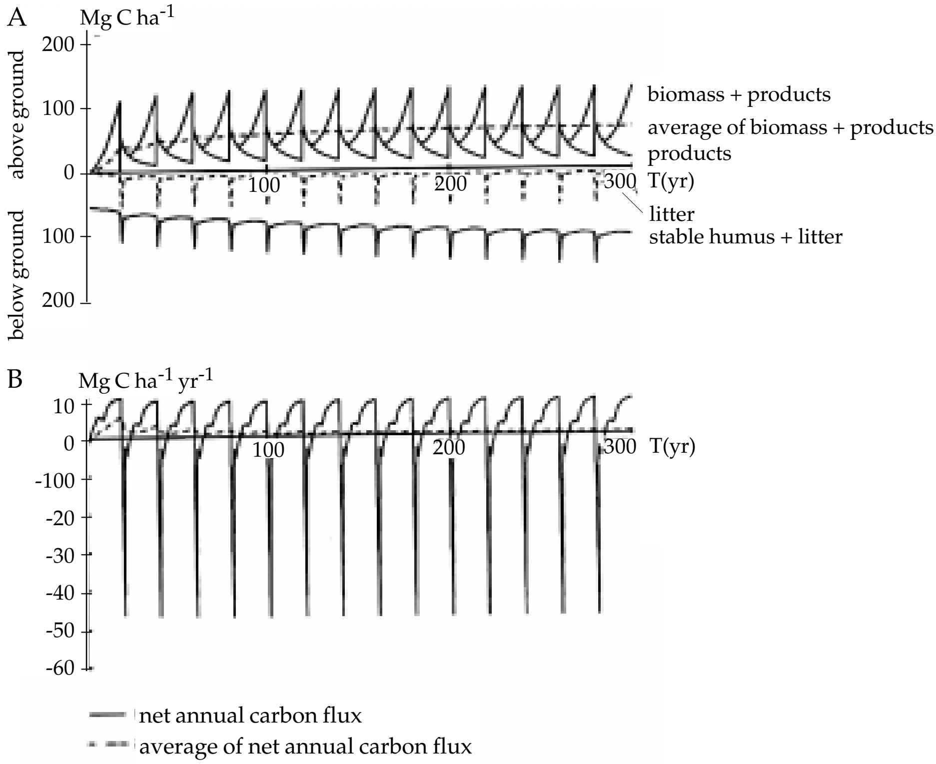

Figure 1. ***A: Carbon stocks in biomass, forest products and soil organic matter for poplar plantations in a rotation of 20 years - an industrial plantation on former agricultural land;***
B: Carbon fluxes both on an annual basis and as a running mean (Nabuurs, 1993).

3. *Quantification of carbon flows in LCA*

In literature about cradle-to-grave analyses of wood products, different ways are used to calculate the CO_2 uptake and the influence of the decay of harvesting wastes. A limited overview is presented in this part. **The presented output of each calculation is the resulting amount of CO_2 that will be allocated to one kg of oven dry matter which can fulfil a economic function.**

In Grasser (1994), different wood chains in Switzerland for energy purposes are studied; the forestry takes place in Switzerland. I picked out one chain to discuss in this paper: the stackwood[1] chain.

- The chain starts with the formation of wood. The calculation of the resulting CO_2 uptake is based on a carbon content of 0.5 kg per kg oven dry matter. This means an uptake of **1.833 kg CO_2 per kg of usable wood**[2]**.**

[1] *Stackwood* (German: Stuckholz) results from thinning activities or is a co-product of the *industrial wood* chain (German: Stammholz). The co-product corresponds to wood (e.g. branches) that has not enough diameter for use as construction material or furniture.

[2] 1.833 = 0.5 x 44/12

- To become 1 kg of usable wood (incl. bark), 1.2 kg of wood has to be cleared; 0.2 kg of wood waste will stay in the forest and will decay. This is 17% of the total growth. The bounded CO_2 will be set free again during this biological decomposition.

Lox (1994) is about folding board on the Belgian market. The 100% virgin fibres cardboard is produced in Scandinavia where the local wood serves as a cradle. The following calculations and assumptions are made to calculate the CO_2 uptake:
- The uptake is also based on 50% of carbon in oven dry matter.
- The biological decomposition of the wood waste is different. 34% of the total growth will stay in the forest, this means 0.5 kg of wood waste per kg of usable wood (incl. bark). The macromolecules of wood are : cellulose (44%[3]), hemicellulose (22%), lignin (26%) and resin (2%). It is assumed that only the cellulose and hemicellulose fraction will decompose, i.e. 66% of the 0.5 kg wood waste. These 0.33 kg of cellulose will set free 0.54 kg[4] of CO_2 in aerobic circumstances.
- The net CO_2 uptake can be calculated as follows: 1.5 kg of total growth gives 2.75 kg of CO_2 uptake, minus 0.54 kg due to decomposition, equals **2.2 kg CO_2 per kg of usable wood**.

IIASA study on a cradle-to-crave analysis of waste paper recycling in Europe deals with the following elements (Virtanen, 1993):
- CO_2 fixation is 0.7 to 0.9 kg for each kg of biomass. In the study biomass means wood incl. water content.
- 65% of the input trees are logs (incl. bark) and the remaining 35% is harvesting waste; 0.54 kg waste per kg of usable wood. The study assumed an anaerobic biodegradation of the harvesting wastes, based on 50:50 volume share for $CO_2 : CH_4$. 0.54 kg harvesting waste produces 0.07 kg CH_4 and 0.23 kg CO_2.
- The calculated net CO_2 uptake for 1 kg of logs (incl. bark and water content) is 0.46 kg CO_2-equivalents[5]. This gives **0.92 kg CO_2-equivalents per kg usable wood** when assuming a water content of 50%.

Dutilh (1994) suggests that the CO_2 uptake due to photosynthesis should be divided by a rough estimate of the age in years of the material that was formed. There, the CO_2 uptake taking place in a production forest for pine wood would have to be divided by a factor of ten to twenty. The CO_2 uptake in this case equals **0.122 kg per kg of oven dry wood**[6].

[3] % = weight/weight oven dry matter

[4] 0.54 = 0.33 x 72/162 x 44/12; cellulose = $(C_6H_{10}O_5)_n$, MM cellulose = 162, M carbon in cellulose = 72

[5] 0.46 = $(0.8 \times 1.54)_{uptake} - (0.23 - 11 \times 0.07)_{decay}$; 11 = GWP for CH_4 in [Houghton 1992] to transform CH_4-emission into CO_2-equivalent emission

[6] 0.122 = 0.5 x 44/12 x 1/15

The last report in this list is about an assessment of the Swedish Forest Industry's contribution to the greenhouse effect (Cooper, 1994). This report does not deal directly with LCA of wood products. The biogenic carbon flows of the Swedish forest ecosystem are described as follows:

- uptake by photosynthesis amounts to	+100 Mton C/yr
- decomposition in the forest gives	-76.7 Mton C/yr
- C uptake due to imported stem wood	+1.3 Mton C/yr
- sum	24.6 Mton C/yr.

The consumption of stem wood in Sweden is ca. 15.0 Mton C/yr (stem wood felling from Swedish forests: 13.6 + imported wood: 1.3). With these data a CO_2

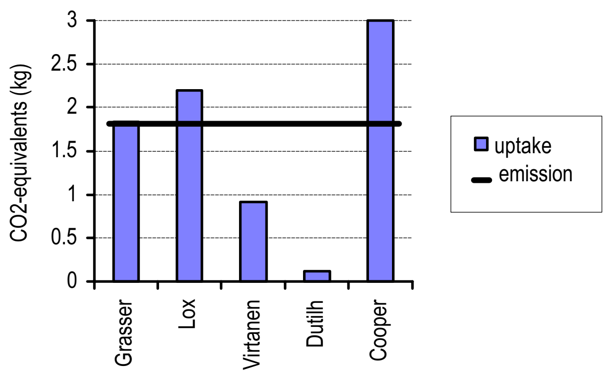

Figure 2. ***Bars: Different ways to calculate the CO_2 uptake by trees and the influence of the decay of the harvesting wastes, allocated to 1 kg usable wood (oven dry matter);***
Line: Emission of CO_2 due to incineration of 1 kg of oven dry matter.

uptake of **3 kg per kg usable wood**[7] can be calculated; this is only relevant for wood used in Sweden.

The bars in Figure 2 show the different ways of calculating the CO_2 uptake, inclusive the influence of the decay of harvesting wastes. The line equals the amount of emitted CO_2 when one kg of usable wood is incinerated. The following can be concluded:

- Grasser has an equilibrium between uptake and emission;
- Lox has a net sink because of a long time frame for composting of the non-cellulose fraction in harvesting wastes;
- Virtanen has a net emission due to the anaerobic decomposition of harvesting wastes (methane has a higher contribution to global warming);
- in Dutilh only five to ten percent of the CO_2 is within a closed cycle;

[7] 3 = (24.6 x 44/12) / (15 x 2)

- the growth level of wood which is higher than the consumption level gives a net sink in Cooper.

3. *Conclusions*

3.1. Is it correct to include CO_2 uptake of trees in LCA ?

An important premise within LCA is the ceteris paribus principle: the generation of a certain function should not influence other activities on this planet (Heijungs, 1992). This means in the context of forestry that as long as the natural process of biomass growing and the carbon stocks remain stationary, independently of the fact that wood serves in different functions, an inclusion of a CO_2 uptake is justified. But this statement is not valid for all forest regions, think of the tropical forests. Also the ratio between historical forest systems and production forests is important from an ecological point of view.

3.2. How should the CO_2 uptake be calculated ?

Referring to the above premise: the inventoried data should be representative for what happens in a balanced situation. By balanced situation I mean an equilibrium between forest growth and use of forest products. Figure 1 shows that carbon stock growth is temporary and that in time the average net flux will become zero. So the approach of Grasser is the most correct one: accounting the carbon content of the used wood. The CO_2 uptake should not be seen as a credit, but as the implementation of the **carbon neutrality** of wood when looking at its life cycle.

The emitted carbon can be present in the form of CO_2, CO, CH_4, etc. Those emissions have a different behaviour towards environmental effects (see approach Virtanen), which can result in different CO_2-equivalents.

The current methodology of LCA as defined in the introduction is not able to deal with the evaluation of the sink-effects of carbon in timber products. For example: when comparing recycling and non-recycling of paper in a LCA, most LCAs show a higher contribution to global warming of the recycling system. This is because recycling systems relays more on fossil fuel consumption. But recycling of paper hold the carbon longer in fixed rotation, this aspect cannot be taken into account in LCA. This is because LCA is a static model (no time aspects).

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ASSESSING THE ECOLOGICAL CARRYING CAPACITY EFFECTS OF RESOURCE EXTRACTION

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Abstract

One of the more challenging aspects of the Sustainable Construction Materials Project was to develop quantitative measures of ecological carrying capacity effects. We define ecological carrying capacity as the ability of an ecosystem to absorb varied effects of resource extraction (e.g. effects on biodiversity, ground and surface water quality, soil stability, wildlife habitat and the carbon cycle). Having first developed estimates of the resources needed to manufacture specific building products, and of the associated energy use, emissions, effluents and solid wastes, we wanted our systems model to also incorporate estimates of the overall ecological carrying capacity effects of extracting the resources. In LCA terms, we wanted to extend from inventory analysis to impact assessment. We did so by distinguishing several dimensions of resource extraction impacts, ranking or scoring different resource extraction activities by dimension, and combining the scores in an index that can be used to weight resource quantity estimates. The scores were developed through a survey of environmental and resource extraction experts.

Introduction

This paper focuses on one aspect of the Sustainable Construction Materials Project, assessment of the ecological carrying capacity effects of resource extraction. This is an important, perhaps critical, area where little has been done previously in life cycle analyses.

Our basic studies for wood, steel and concrete building products included energy for resource extraction, related atmospheric emissions and wastes. The results of these studies provided data for aggregating the environmental effects of specific building designs within a systems model. But the studies did not include the many other environmental effects associated with timber harvesting, mining and quarrying. Yet these effects are often the primary focus of environmental concern on the resource extraction side, particularly for wood products. Also, producers of other products feel they have a definite advantage over wood in terms of resource extraction impacts and would not consider comparisons fair if we did not take these effects into account.

In LCA terms, we had to advance from inventory analysis to impact assessment in this critical area. Deciding how to make that advance was a challenge from the beginning of the project. While we consider the approach and results so far to be promising, they should be viewed as the first steps in a longer term research effort.

The problem

Our starting premise is that resource extraction activities have to be undertaken with a view to the ecological carrying capacity of the relevant ecosystems. We define ecological carrying capacity as the ability of an ecosystem to absorb the varied effects of resource extraction. The term obviously encompasses a broad and diverse range of potential effects. For example, it includes effects on:

- biodiversity;
- ground and surface water quality;
- soil stability and regenerative capacity;
- wildlife habitat; and
- the carbon cycle.

We implicitly consider ecological carrying capacity to be a natural resource with limits like any other. The limits define the point after which irreversible or serious damage would occur.

The problem is that while we think ecological carrying capacity effects are as important as other more readily quantified resource inputs and waste outputs, these effects are much harder to incorporate. The difficulties reflect such considerations as:

- the large number of different types of effects;
- the fact many are not measured or are not consistently measurable;
- our inability to compare measures across impact types;
- the requirement for value judgments or trade-offs because an environmental loss from one perspective may be a gain from another (e.g. wildlife habitat);
- conflicting scientific evidence or lack of scientific agreement; and
- variations in impact levels and implications depending on location, resource extraction methods, remedial actions and other very specific conditions.

The last point about location and other factors that determine impact levels is particularly critical for a model like ours. Even with full scientific agreement and ample data, it might be impossible to incorporate many of the effects in specific terms because our model deals with very large geographic areas and average or typical extraction techniques. We therefore had to find some other means of quantifying the combined ecological carrying capacity effects.

The survey solution

We started with an overview study of ecological carrying capacity effects, undertaken by Dr. Robert Paehlke. While wood, steel and concrete industry specialists were developing inventory analyses (unit factor studies) which included the more readily quantifiable effects of resource extraction - resource volumes, energy use, emissions and effluents - Dr. Paehlke's task was to identify, assess and compare the critical ecological carrying capacity impacts on a qualitative basis. He was also asked to assess the potential for quantification and to recommend an approach.

Dr. Paehlke concluded it would not be possible to develop measures comparable to those for other more precisely defined impact categories. He recommended a survey and scoring approach as an alternative. Dr. Paehlke specifically suggested we:

- distinguish several dimensions of resource extraction;
- rank or score different resource extraction activities by dimension;
- combine the ranks or scores in an index; and
- apply the index to the quantities of resources for each construction product.

He suggested we survey environmental and resource extraction experts to develop the scores, perhaps using the Delphi technique. We opted instead for a straight-forward survey of experts, with the possibility of a follow-up survey if needed.

A pre-selected panel of 30 experts were provided with background information and then sent a pretested written questionnaire with an accompanying guide. Twenty-three of the 30 experts eventually completed and returned the questionnaires.

None of the panelists were currently employed by relevant industries or industry associations. In general, all panelists had some expertise with regard to all the extraction activities of interest, but expertise levels were higher overall for timber harvesting followed by aggregates extraction. Timber harvesting literature far outweighs literature on the environmental effects of other extraction activities and it is therefore hard to be an environmentalist without being exposed to timber harvesting issues. Most panelist were also specialists in specific fields or with regard to specific issues such as biodiversity, water pollution, and environmental impact assessment generally.

In the survey, panelists were asked to consider the ecological carrying capacity impacts of six resource extraction activities - timber harvesting in coastal British Columbia, timber harvesting in the boreal forest and British Columbia interior, iron ore and coal mining, limestone quarrying and aggregates extraction — in terms of four impact dimensions —intensity, extent, duration, and significance.

> *Intensity* refers to the degree of overall environmental disruption – how much of the ecology of an area is disrupted either temporarily or permanently by extraction activities.
>
> *Extent* is self-explanatory and is the one dimension that can be measured fairly easily. We asked panelists to think in terms of the extent of areas typically impacted directly or indirectly per unit of resource extraction.
>
> *Duration* refers to the average length of time before impacted areas return to ecological productivity and balance, even though this seldom represents a return to the exact pre-extraction conditions. Panelists were asked to take account of typical regeneration or restoration practices.
>
> *Significance* refers to such considerations as the uniqueness of areas typically impacted, their ecological richness, and their beauty or aesthetic value.

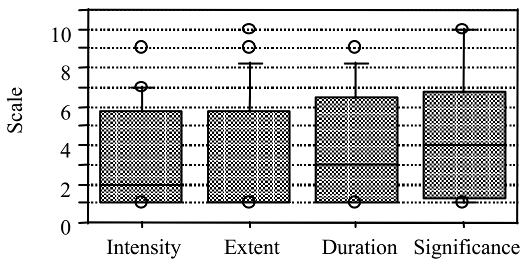
We stressed the relative aspect of the responses throughout. Respondents were to consider the various extraction impacts relative to each other and not to any other activities or environmental concerns.

The questionnaire was divided into three parts. In Part I respondents were asked to rank the importance of the four dimensions relative to each other. We thought answers to questions in this part might provide a basis for weighting scores from Part II. The four questions in Part II – one for each dimension – were the main focus of the questionnaire. For each dimension, respondents were asked to score the relative impacts of the six extraction activities on a scale of 1 to 10. The emphasis was on relative impacts and panelists were instructed to score at least one activity at the 1-level. Part III of the questionnaire simply provided information on the panelists, including self-ranking of their expertise levels.

Survey results

The small sample size limited our choice of descriptive statistics and our ability to apply statistical significance tests. We have also tried to be cautious about how we interpreted and used the results because of the very subjective nature of the responses.

We decided to use distribution medians as the primary measure of central tendency and as the overall 'panel' score for each question. We did not use arithmetic means because they would be too heavily influenced by outlier values when the sample size is so small. Assessing the degree of consensus or convergence was more difficult and we finally settled on interquartile ranges (IQR) as the main indicators. Some response distributions were so convergent that we were able to use those IQR's as control values and develop rules of thumb for assessing convergence in other distributions. But in general, we put more emphasis on distribution shapes and patterns than on any statistical measures.



Descriptive Statistics

	Mean	Median	IQR
Intensity	3.260	2.000	4.750
Extent	3.521	1.000	4.750
Duration	3.695	3.000	5.500
Significance	4.478	4.000	5.500

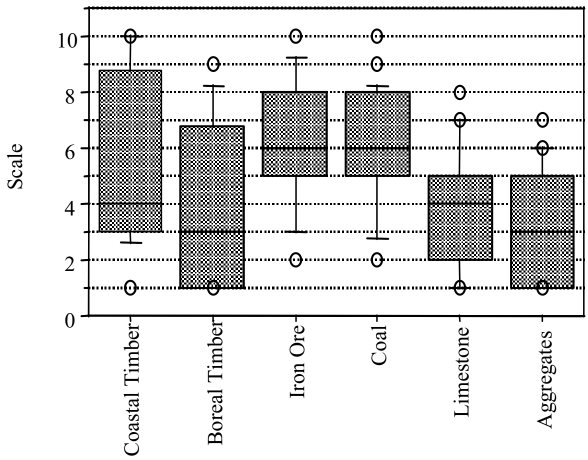
Figure 1. ***Relative importance of dimensions.***

Most of our results are shown in the form of box plots, although the report also includes histograms for all distributions. For example, Figure 1 shows the box plots for the question about the relative importance of the four dimensions. The vertical axis shows the 1 to 10 scoring scale and the plot shows the distribution of scores, with one plot for each dimension. The shaded area of each plot shows the IQR (50% of the responses). The side table in the figure shows the medians and IQR's for the individual distributions. The medians are also shown by the horizontal lines across the shaded part of the plots.

These plots show that overall the panel scored the extent dimension as least important, followed by intensity, duration and finally significance. This seems to be a sensible pattern, but there was little convergence so we did not feel we could put much weight on this set of responses.

Figure 2 shows the results for the question about the relative intensity of extraction activities. Based on medians, the panel ranked boreal timber harvesting and aggregates extraction as the least intensive activities, with coastal timber harvesting and limestone quarrying ranked second. Iron ore and coal mining were equally ranked as relatively intensive activities. There is an intuitive logic to these results and we see the same sense of logic throughout the other dimension scores. We are encouraged by that aspect of the results.

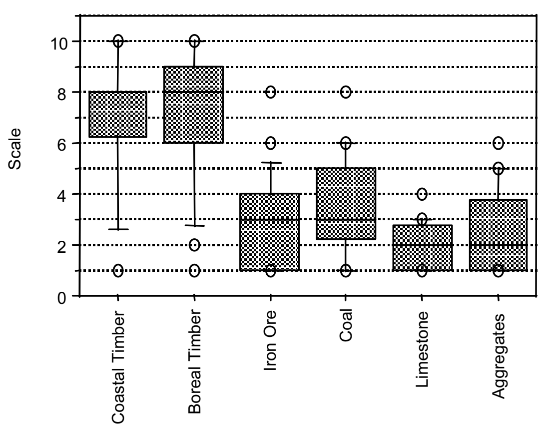
The IQR's in Figure 2 are quite reasonable for all but the timber harvesting activities, with 50% of the responses within +/- 2 of the medians. The larger IQR's



Descriptive Statistics

	Median	IQR
Coastal Timber	4.000	5.750
Boreal Timber	3.000	5.750
Iron Ore	6.000	3.000
Coal	6.000	3.000
Limestone	4.000	3.000
Aggregates	3.000	4.000

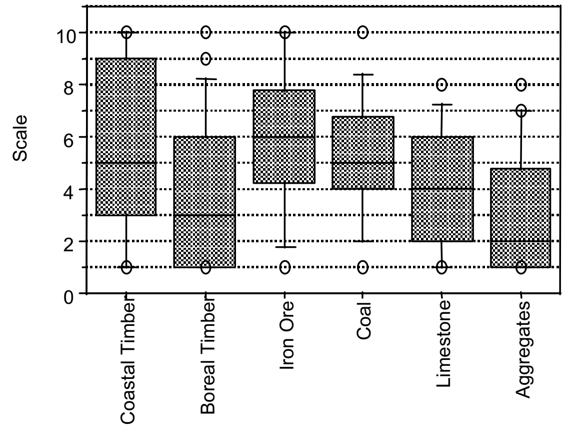
Figure 2. ***Intensity scoring.***



Descriptive Statistics

	Median	IQR
Coastal Timber	8.000	1.750
Boreal Timber	8.000	3.000
Iron Ore	3.000	3.000
Coal	3.000	2.750
Limestone	2.000	1.750
Aggregates	2.000	2.750

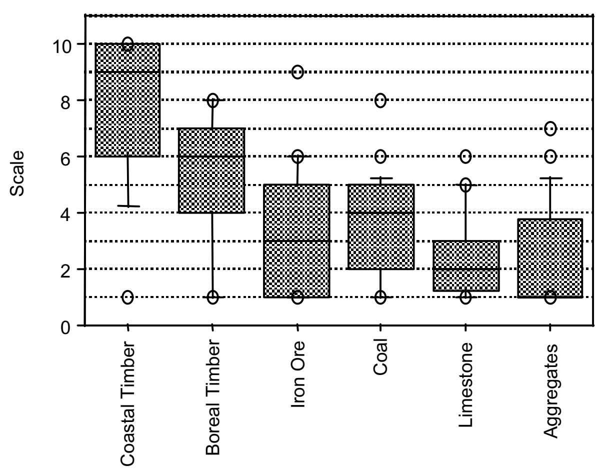
Figure 3. ***Extent scoring.***



Descriptive Statistics

	Median	IQR
Coastal Timber	5.000	6.000
Boreal Timber	3.000	5.000
Iron Ore	6.000	3.500
Coal	5.000	2.750
Limestone	4.000	4.000
Aggregates	2.000	3.750

Figure 4. Duration scoring.



Descriptive Statistics

	Median	IQR
Coastal Timber	9.000	4.000
Boreal Timber	6.000	3.000
Iron Ore	3.000	4.000
Coal	4.000	3.000
Limestone	2.000	1.750
Aggregates	1.000	2.750

Figure 5. Significance scoring.

for timber harvesting indicate less panel consensus. In fact, the underlying histograms show distinct splits in the distributions with one grouping toward the high end of the scale and another toward the low end.

In the case of the extent dimension (Figure 3), response convergence was very good. As expected, the panel considered timber harvesting to be a quite extensive activity while all of the other activities were ranked relatively low on the scale.

The duration scores (Figure 4) repeat the IQR pattern we saw with the intensity dimension - little panel consensus about the relative duration of timber harvesting activities. The histogram for coastal timber again shows two distinct groupings of responses - one oriented to the low end of the scale and one to the high end.

Figure 5 shows the set of responses for the significance dimension. As might be expected, coastal timber harvesting (which encompasses the British Columbia rain forest) was scored very high on the significance scale. In this case, convergence for the coastal timber scores was better than the box plot indicates: 16 of the 23 respondents scored coastal timber in the 8 to 10 range, with 9 accounting for a mode of 10.

Figure 6 shows the distinct split in the histograms for the intensity scores, mentioned earlier. We found a very similar pattern in the coastal timber histogram for the duration dimension. We think these results partly reflect two different schools of thought about the impacts of timber harvesting. One school views timber as a renewable resource, arguing that harvesting does not result in dramatic landscape changes unless there is serious erosion and that proper regeneration makes it difficult for people to even know whether an area has been logged after a generation or so. The other school focuses on the forest instead of the trees, arguing that the original forest and ecology is never renewed: an argument that has particular appeal with regard to old growth forests.

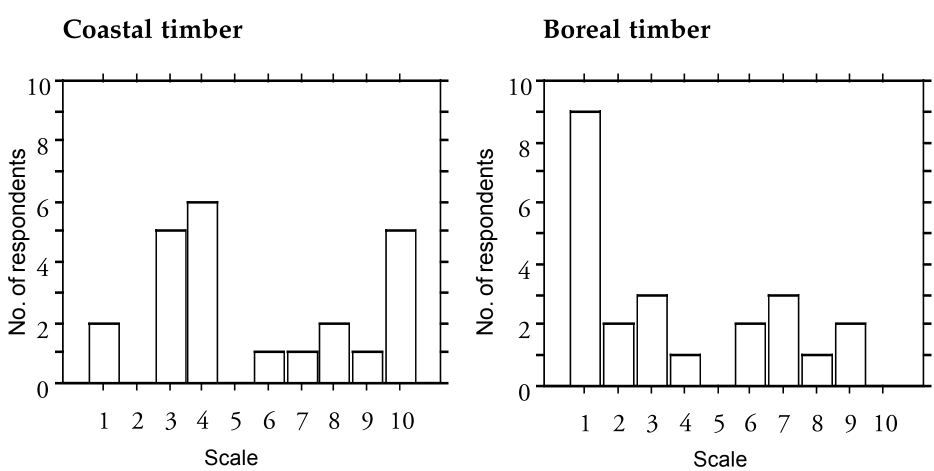


Figure 6. Timber intensity.

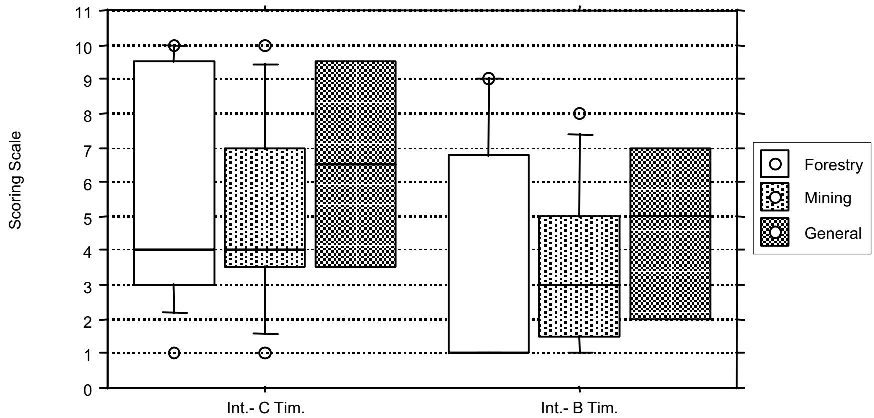


Figure 7. Intensity by expertise category.

To further understand the responses, we broke them down by broad expertise categories. Figure 7 shows the breakdown for timber intensity. Very few respondents are in the generalist category so it should be ignored. The notable point is that those classifying themselves as primarily timber harvesting experts tended to be much more divergent in their responses. We found similar splits for other timber harvesting results.

We think one important reason for the divergence among timber harvesting experts is the great variation in forests, harvesting conditions and techniques across Canada. Experts are more likely to be aware of the resulting differences in environmental impacts and their responses probably tend to reflect situations in regions with which they are most familiar. For that reason we plan another survey with regional panels instead of a national panel.

Using the results

Table 1 summarizes the median scores by dimension for each harvesting activity. The sum of the medians for each activity gives an indication of the overall panel judgment about the relative ecological carrying capacity impacts of that activity. As the totals indicate, the panel considered aggregates extraction to have the least relative impact and coastal timber harvesting the greatest relative impact.

We tried two different methods of using the scores for the relative importance of the four dimensions as weights or multipliers attached to the activity scores. But we found practically no change in terms of the ranking of the six activities, and the

Table 1. Total impacts by activity.

Median extraction activity impact scores: by dimension and total

	Impact intensity	Extent of the area impacted	Impact duration	Significance of the area impacted	Total impact
Costal timber harvesting	4	8	5	9	26
Boreal timber harvesting	3	8	3	6	20
Iron ore mining	6	3	6	3	18
Coal mining	6	3	5	4	18
Limestone quarrying	4	2	4	2	12
Aggregate quarrying	3	2	2	1	8

Table 2. Conversion to a simple index.

	Impact index
Aggregates extraction	1.00
Limestone quarrying	1.50
Coal mining	2.25
Iron ore mining	2.25
Boreal timber harvesting	2.50
Coastal timber harvesting	3.25

Table 3. Applying the index - illustrative calculation: wood and steel designs of a 3m x 30m wall.

	Resource use (kg)		**x Impact index**	**= Weighted use**	
Resource	**Wood wall**	**Steel wall**		**Wood wall**	**Steel wall**
Wood fibre	598		2.50	1,495	
Limestone		77	1.50		116
Iron ore		508	2.25		1,143
Coal		251	2.25		565
Totals	**598**	**836**		**1,495**	**1,823**

proportional increase in weighted compared to unweighted scores was almost the same for every activity. These conclusions were not affected by the weighting approach. In fact there was almost no absolute difference in the results using one weighting approach versus the other. We considered these outcomes to be especially remarkable in view of the subjective nature of the entire exercise.

In view of these findings, we decided to stick with the simplest set of results – the unweighted median totals for each activity. We further simplified the arithmetic by developing a simple index that more readily shows the relative impact results (Table 2). Aggregates extraction was scored lowest so we arbitrarily assigned it an index value of 1. All other medians were divided by the total median score for aggregates extraction to derive the other index values.

One way of interpreting these results is to say that limestone quarrying was judged to have 1.5 times the impact of aggregates extraction while coastal timber harvesting has 3.25 times the impact. Another way of expressing the results is to say that, from an environmental perspective, the extraction of 3.25 cubic meter of coastal timber is about equivalent to the extraction of 1 cubic meter of aggregates. Either interpretation is, of course, subject to the caveat that the index reflects a subjective survey of a small panel.

Table 3 illustrates how we apply the index in our systems model. The table shows estimated raw resource requirements for a simple stud wall designed in wood and in steel. The first two data columns show the estimated resource requirements before applying the ecological capacity index numbers shown in the center column. The last two columns were generated by multiplying the basic resource requirements by the index numbers. These estimates might be called ecologically weighted resource requirements.

The key point is that the environmental implications of quite different types of resource requirements to build the example wall can now be compared in a meaningful way.

In the example, the original estimate of resource requirements was less for the wood design than for the steel. The gap was closed somewhat by application of the index. However, if we had applied the index for coastal timber instead of that for boreal timber, the ecologically weighted resource requirements would have been lower for the steel wall design. But in general, we feel impacts may tend to be more a function of the sheer mass or volume of resource required than of the impact index numbers.

Overall, we think the study is a step in the right direction. We can’t wait for scientific certainty or hard ecological carrying capacity impact data before we include resource extraction impacts in life cycle analysis.

THE ENVIRONMENTAL LOAD OF FOSSIL FUELS IN SWEDISH FORESTRY - AN INVENTORY FOR A LCA

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Abstract

This is a preliminary report from a study in progress performed within the framework of the Nordic Wood programme (Nordisk Industrifond) in co-operation with the Swedish Institute of Wood Technology Research. The purpose of this study is to present reliable data concerning the consumption of fossil fuels in Swedish forestry during the early 1990's.

Background

A product life assessment (LCA) is an assessment of the total environmental impact caused by a certain product during its lifetime (Anon, 1992). Wood is used in a number of applications. Modern and relevant data are needed in order to facilitate a comparison of the impact of wood used in relation with the use of other materials. It is here assumed that a large proportion of the environmental load from forestry lies in the fact that its operations are dependent on techniques that use fossil fuels.

Swedish forestry has long been identified as an energy system. Its ability to produce a surplus of energy was mandatory for the Swedish mining industry and society (Sundberg et. al., 1995) from its outset. In the middle of the 70's, comprehensive energy studies of Swedish forestry were carried out (Renborg & Uhlin, 1975; Genfors & Thyr, 1976). Sundberg presented (1982) a study that proposed fuel consumption to be a cost determinant for machine works in forestry.

By the middle of the 1970's, mechanisation in Swedish forestry had completely replaced horse-drawn hauling to truck road with the use of forwarders or skidders. However, the felling technique was predominantly motor-manual, although processors and delimbers were later introduced. In contrast, Swedish forestry of the 1990's is characterised by a complete, respectively dominating, mechanisation of final felling and thinning. The load constituted by the use of fossil fuels might therefore have been changed since the 1970's.

Acknowledgements

This study is performed within the frame of the Nordic Wood programme (Nordisk Industrifond) in co-operation with The Swedish Institute of Wood Technology Research in Stockholm. Scientists at the Forestry Institute of Sweden, involved in procuring data for this study, have been G. Andersson, B. Brunberg, S. Mattson, H-Ö Nohrstedt, S. Scherman and the author.

Purpose

The purpose of this study is to present reliable data concerning the consumption of fossil fuels in Swedish forestry during the early 1990's. This is aimed at being the first step in a LCA inventory that will also contain an appreciation of the use of fertilisers, pesticides and other chemicals. When necessary data for a LCA is obtained, such analyses can be done concerning the use of wood in different applications but also as a means to evaluate the environmental load that is constituted by different forestry practices. A hypothesis is that clear felling, for example, could be compared to a type of a selection cutting pattern, as well as it is possible to compare to different methods of regeneration.

The functional units for an extended use of LCA in this context are therefore two: Load per volume-unit of wood or fibres, (with respect to the use of wood) and load per hectare of forest land (with respect to the immediate impact on nature).

Scope

The scope of this study is defined as starting with practises or actions that bring personnel and machinery to the area in the forest where a certain operation is to be performed. An operation is defined as the motor manual- and/or the machine-work of the operation itself, as well as the move between sites. The boundary towards the end user is drawn at deliverance at industry. The analysis will not contain resources used to feed and dress people, nor will it quantify the energy labour spent while working. This report is to be regarded as a preliminary documentation of a not yet completed inventory, particularly with regard to the calculation of emissions.

Methods and data availability

1990 is a very suitable period for this kind of analysis. Due to pressure from the public and export markets, which to a certain degree is a result of the work of the Brundtland Commission, a change in Swedish forestry policy was proposed and analysed. Until this time the primary aim of forestry was to produce wood for industrial purposes. In this context, comprehensive studies were carried out on the condition of the forests, as well as studies on the effects and by-effects of a change which also aimed to preserve or develop the natural biological diversity. A computation of annual allowable cuts for ten consecutive ten-year periods was made, beginning in 1988 (Lundström, Nilsson & Söderberg, 1993). This study (AVB 92) gives a controlled picture of the volumes given under the present forestry policy, if the policy prevailed. The study shows the allocation of wood available for harvest between thinning, final felling and species for four wood balance/ computation regions (Bo1 - Bo4), ranging from the north to the south of Sweden.

Areas treated with regeneration measures are also described. In this study, the results from the computations (with amendments for an increased use of selection type felling in the early 1990's) will serve as a norm for the output of wood from the Swedish forestry system during the early 1990's. The workload needed to achieve this production of wood is evaluated by using productivity estimates presented by Hellström & Westerberg (1991) and Freij & Tosterud (1989). This workload is transformed to the consumption of fossil fuels by using data collected by Landström (1994). His evaluation of fuel consumption per hour of machine-work is founded on his own measurements and statistics from forest enterprises and authorities. The principal flow of fossil fuels is described in the flow chart in Figure 2.

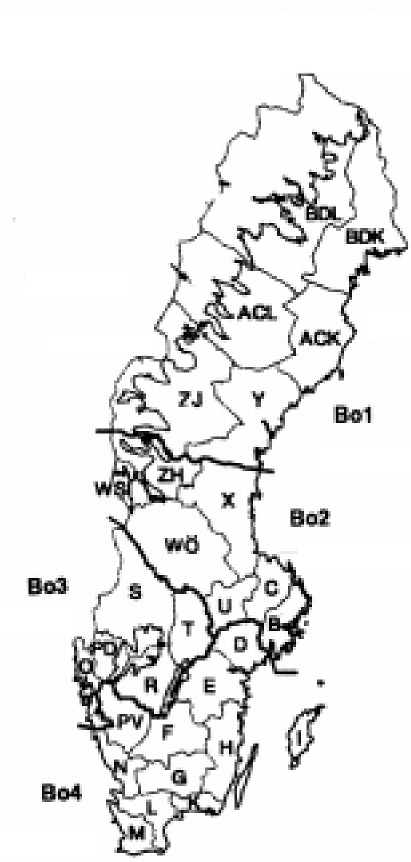

Figure 1. Regions of balance, computation regions for analyses of annual allowable cuts in Sweden (Bo1 - Bo4) in AVB '92.

Fuel consumption	**Regeneration** Cut-over clearing Site preparation Artificial regeneration Spacing and cleaning Draining Fertilising **Logging** Thinning Final cutting Selection cutting	- work on the site - daily transportation of personnel to work area - moving between sites, personnel and machines - transportation of material needed - transportation of foremen to work area
	Transportation to industry Road transport Rail transport	

Figure 2. Flow diagram, showing consumption of fossil fuels.

Results

In regeneration operations (Table 1), the bulk of the diesel consumption occurs in scarification, which is a completely mechanised operation. Petrol consumption prevails in other operations. A large proportion of the estimated use of petrol occurs when personnel and equipment are moved between sites and to their daily work (which is the sole case for the use of petrol in scarification and manual planting). It is evident that the use of fossil fuels for purposes other than direct work is considerable in regeneration operations.

The use of diesel oil is dominant in logging. Values in the table express a slight tendency to fuel needs per harvested volume being higher in selection cutting systems.

According to national statistics (Anon, 1994), about two thirds of the annual haulage of wood from forest to industries, expressed as ton kms, is carried out by road transport. The remaining transportation is carried out by rail. The historical averages, according to statistics, give averages that are applied to the net harvested volume according to AVB '92, 52.71 million cubic meters of solid wood of 63.43 (incl. bark), harvested and removed from site. The road transportation is calculated to consume 75 000 m^3 diesel oil. The use of fossil fuels for railway transportation is dependent on the extent to which the trains are driven by diesel or electrical locomotives, and the source of the energy for the latter. An appreciation, made with the aid of the national railway company, of some emissions for the transportation of round wood, is presented in Table 3.

A calculation of some emissions for NO_x, CO, CO_2 and HC from forestry and roundwood haulage to industry, is presented in Table 4. It is then assumed that diesel and petrol gives emissions corresponding to values presented in Table 5 for operations in regeneration and logging.

Table 1. Consumption of fossil fuels in regeneration operations according to calculations. All Sweden 1988-1998.

Operations	Treated area, 1 000 ha	Consumed amount of	
		diesel oil, m^3	petrol, m^3
Cut-over clearing	178		970
Site preparation	142	1 220	370
Artificial regeneration[1]	138		1 770
Spacing and cleaning	134	140	1 500
Draining	11	110	50
Fertilising	9	20	10
Sum	612	1 490	4 670

[1] Fossil fuels used for the production and transportation of seedlings are omitted here.

Table 2. Consumption of fossil fuels in logging (felling and hauling to roadside) operations according to calculations. All Sweden 1988-1998.

	Final felling	Thinnings	Selection cutting	Total
Volume removed, mill m^3 solid wood incl. bark	35	18	10	63
Area treated, 1 000 ha	140	256	115	511
Oils and fuel for logging, work on site, 1 000 m^3				
- diesel,	60.2	28.3	19.1	107.6
- petrol,	2.5	5.1	0.8	8.5
-oils[1]	1.3	2.7	0.2	4.2
Moving between sites 1 000 m^3, diesel				18.3
Travel to work 1 000 m^3, petrol				5.7
Total amount 1 000 m^3 of				
-diesel				130.1
-petrol				14.4

[1] Lubricants and hydraulic oils, an incomplete assessment.

Table 3. Emissions[1] for roundwood haulage on roads and railways.

	Work, mill ton km	Emissions, tons			
		NO_x	CO	CO_2	HC
Roundwood vehicles	3 380	2 370	811	179 195	202
Electrical driven trains	1 375	2.5	1.5	1 375	0
Diesel-electrical driven trains	345	121	32	8 703	52
Sum	5 100	2 490	844	189 271	254

[1]Emissions are calculated by G. Andersson according to (Andersson, 1994; Anon, 1993; Trouvé,1995; Landström, 1994).

Table 4. ***Calculated values for some emissions[1] from Swedish forestry 1988-1998, tons and % of total.***

	NO_x		CO		CO_2		HC	
Regeneration								
- diesel	74		23		3 890		7	
- petrol[2]	88		1 326		9 555		132	
Sum	162	***2***	1 349	***18***	13 445	***2***	139	***9***
Logging								
- diesel	6 292		1 963		328 450		629	
- petrol	267		3 184		28 705		318	
Sum	6 560	***71***	5 147	***70***	357 155	***64***	947	***61***
Hauling to industry	2 490	***27***	844	***12***	189 271	***34***	450	***30***
Sum	9 212	***100***	7 340	***100***	559 871	***100***	1 542	***100***

[1] Lubricants and hydraulic oils are omitted.
[2] Emissions from petrol are calculated as dominantly originating from terrain transportation vehicles.

Emissions from regeneration are low with respect to NO_x and CO_2. The common use of petrol there is the cause of a high proportion of the emitted CO. Data in this table indicates that measures to reduce emissions should, in the first place, be directed to logging operations. In the second place the use of roundwood vehicles for hauling to industry is the target.

The impact of emissions may differ depending on the entity they are referred to. In Table 6, some emissions are allocated to three different entities that seem, by the author, to be logical. The impact will differ depending on the kind of forestry we are looking at. It is quite possible that intensive forestry, which produces a lot of volume from a small area, will have a higher environmental load per hectare, but possibly a lower load per volume unit produced, when compared to traditional boreal forestry, for example.

This is illustrated in Table 7 where comparisons are made between calculated emission data for balance regions Bo1 (North Sweden) and Bo4 (South Sweden). The data does not include haulage from forest to industry, as this operation can not easily be allocated to balance regions (Bo). If the environmental load of CO_2 is to be evaluated according to this study, it is fair to conclude that northern forestry has a lower environmental load when the emission is compared to annually treated area or productive forest land. On the other hand, its impact will be marginally higher when the emission is referred to the amount of wood harvested and removed. The ambivalence in interpreting the results does not mean that the comparison is meaningless, on the contrary, it stresses the importance of the choice of functional unit being adequate, in regard to the aim of the study.

It might be surprising to note that completely mechanised scarification causes a similar magnitude of CO_2 emissions per treated hectare as those caused by a completely manual planting operation, Table 8. The reason for this is the amount of transportation work spent on bringing personnel to the work site. An inclusion of fossil fuels for seedling production will increase the calculated environmental load of artificial regeneration. A comparison between motor-manual and mechanised

Table 5. Emission factors used, tons/m^3 fuel in regeneration and logging. (Anon, 1990).

	Diesel	Petrol
NO_x	0.054	0.019
CO	0.016	0.284
CO_2	2.610	2.046
HC	0.005	0.028

Table 6. Emissions expressed in different ways.

Emissions, kg per	NO_x	CO	CO_2	HC
Solid m^3 delivered to industry	0.17	0.14	10.62	0.03
Annually treated area forest ground, 1 000 ha (1.123 mill ha)	8.2	6.5	498.5	1.4
Productive area forest land, 1 000 ha (21.84 mill ha)	0.4	0.3	25.6	0.1

Table 7. Comparison of calculated emissions in Bo1 and Bo2 for regeneration and logging operations in 1988-1998.

	Bo1 (north)	Bo4 (south)
Consumed volume, m^3		
- diesel	37 600	36 500
- petrol	3 840	6 030
Emissions CO_2, tons	106 300	107 600
Volume removed mill m^3 solid wood	18.23	20.43
Area annually treated, 1 000 ha	410	290
Productive area forest land, mill ha	9.74	4.45
Emitted kg CO_2 per		
- m^3 solid wood incl. bark	5.8	5.3
- treated 1 000 ha	260	370
- 1 000 ha productive land	11	24

Table 8. Calculated emissions of CO_2 from some regeneration operations in Northern Sweden (Bo1), 1988-1998.

	Diesel oil, m^3	Petrol, m^3	CO_2, ton	Area, treated, ha	CO_2 kg/ha
Mechanised scarification	470	130	1 500	64 000	23
Artificial manual regeneration (planting)	0	490	990	57 000	17
Motor-manual cleaning and spacing	0	520	1 050	56 100	19
Mechanised cleaning and spacing	23	7	75	900	83

spacing/cleaning shows that the present organisation for mechanisation gives a substantially higher environmental load per hectare treated.

Discussion

Methods for the use of LCA techniques are at present developed within the ISO 14000 scheme. Realising the pressure from the Rio summit, the industry needs a practical tool for making the same kind of analyses with regard to environmental impact, as it already has for the analysis of the use of capital or labour. LCA or similar might therefore be a tool used generally in product development. In EPS (Environmental Priority Strategies Product Design), for example, a material is designated a certain environmental load factor for its production, use and scrapping. If there is lack of such information for wood, there would be a risk of wood not being regarded as a possible material to use since its environmental impact cannot be declared. The risk that erroneous load values are designated to wood is evident if they are calculated by scientists who are not familiar with forestry or the forest industry. The involvement of forest science is important in developing LCA.

Apart from this, there is scope for several applications of LCA in forestry:

- Analyses of environmental bottlenecks. In urban areas, methods that give low environmental load per hectare might be preferred; in a more production oriented forestry the preferred option is the use of methods that give low load per volume produced.
- Analyses of regional differences as well differences between different forestry systems such as even aged, managed forests compared to different applications of selection cutting. LCA methods can here be one of many instruments used in order to measure the sustain ability of forestry.
- When developing new organisations, methods or techniques, its environmental load can be discussed from the aspect of LCA .

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LCA and Wood Products

LIFE CYCLE ANALYSIS OF WOOD PRODUCTS

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Abstract

During the last two decades, Life Cycle Analysis was developed as a tool to evaluate the environmental impact of products and processes. This paper gives a brief history on how this and related methods have been applied on wood-based products. Modules and processes evaluated in recent studies are listed and the important results are summarized. The benefits and limitations of forest products in LCA studies are illustrated and future research tasks are outlined.

Introduction

In the following paper, an overview is given on recent developments in LCA of wood products. Although LCA is a relatively new approach to scientifically measure and evaluate the environmental aspects of products, many case studies and applications have already been realized on wood and timber-derived products. As a consequence, this review cannot refer to all studies and projects accomplished in this area, because not all data and results have been published and some information, especially when collected in companies, is not always a public domain. It must be an aim of the workshop to gather the information on completed or ongoing projects regarding wood or forest industry products in the proceedings for a more comprehensive 'state of the art' report.

The paper is structured in the following way, with reference to the topics given to the authors by the organizing committee:

1. Type of analysis carried out regarding LCA of wooden products
2. Summary of main results
3. Strong and weak points of LCA studies and
4. Future research tasks

Type of analysis carried out regarding LCA of wooden products

Taking the LCA concept of SETAC (1993) or the working drafts of ISO TC 207/ SC5 as a framework, one has to admit that only very few studies on wood products do fulfill those requirements of a 'real' LCA, that means 'cradle to grave' analysis. As it is often the case when relatively new techniques are under the process of development, the LCA methodology has been adapted and improved step by step parallel to the first practical applications. As a consequence, most of the studies published so far cannot directly be compared to each other, due to:

- different system boundaries, goal definitions and scopes
- different quality of basic data used
- different assumptions and cut off criteria
- regional differences

This does, of course, not mean that all studies completed so far are worthless but it is likely that the information gathered in the different case studies have to be checked, updated and adapted, if possible, to fit in a more generally accepted framework.

Until today, the following environmental parameters have been analysed in the field of wood products:

In the wood industry, as well as in other industry sectors, environmental concern started to raise in the mid 1970's after the two energy crisis. Consequently, most projects accomplished in the late seventies and in the eighties have focused on the energy consumption of the manufacturing processes and the resulting products. The first outstanding contributions was the so called CORRIM (1976) report published for the US market. CORRIM stands for 'Committee on Renewable Resources for Industrial Materials' and the report presents material balances and energy required for the manufacture of ten wood commodities frequently used and of possible substitute materials. Quantitative data on energy requirement for the production of wood and wood based products compiled a study realized at the Federal Research Center of Forestry and Forest Products under the guidance of A. Frühwald between 1983 and 1985 (BFH 1986). This study gives a comprehensive overview on the energy consumption within the German wood processing industry, based on a detailed questionnaire sent to representative plants and manufacturing units.

Triggered by the so-called Forest decline discussion and further dramatic changes of the global climate condition, it became obvious that the quality of our air, water and soil is at grave risk. Scientists realized that energy calculations alone were not adequate for describing the environmental qualities of processes and products. More parameters for an environmental evaluation were needed, as for example emissions to the air, water or soil.

First analysis conducted at the end of the last decade took into consideration the impacts of emissions to the environment, calculating so-called critical media volumes. They had to base their results on very sparse data of air emissions of manufacturing and combustion processes. We at EMPA calculated the primary energy consumption for 5 wood-based materials and used the threshold limit values of six air pollutants given in the Swiss Clean Air act to denominate the critical air volume. Because CO_2 is not regarded as a toxic gas, there is no threshold value given in the environmental legislation, so that the positive CO_2 characteristics of wood were not reflected in those figures. This aspect has been focused in many other studies by calculating and comparing CO_2 emissions of wood and alternative products (Wegener et al. 1994). In addition to the CO_2 emissions of combustion processes several authors also contribute to the carbon-storage of long-lasting wooden products as a sink-effect to underline this important benefit of timber utilization.

According to recent developments of the evaluation methodology, so-called problem-related effect-score models (Heijungs et al. 1992) are proposed were emissions with similar environmental effects are grouped and their impact is scaled in relation to a guide emission (CO_2 for Global Warming, SO_2 for acidification, phosphate for nutrification, ethylene for ozone depletion a.s.o.).

Parallel to the developments in the inventory assessment, the scientific community demonstrated that analysing on the manufacturing process alone is not sufficient to show up the entire environmental burden of products or processes. Impacts in other stages of the products life could be as or even more decisive than the process of manufacturing. Today is generally accepted that an ecological assessment of products has to analyze and evaluate all stages of the products life from 'cradle to grave', especially when a comparison between alternative products is conducted.

This is easy to demand but very difficult to realize in practice because the data demand is intensive. Even within the forest products sector, most processing steps became quite complex, especially when entering the second transformation sector. As a consequence, it is common sense to divide the whole life cycle of a building component or a furniture in useful subprocesses or modules and elaborate input-output data for each of those modules. That is the reason why most data published so far are covering selected steps of a LCA, like timber harvesting, lumber production, gluelam or panel processing. Those modules provide the input data for studies where complete products are investigated and compared with substitutes. Here one must consider that almost all modern wood products are composites, that means combinations of various materials. All the co-materials and ancillaries have their own environmental burden which have to be known for a total assessment of the main product.

In Table 1 an overview is given on processes, modules and LCA studies of wood and wood-based products realized in the European countries within the last decade.

In summary, most studies on forest products presented so far focused on the energy use as key parameter to evaluate the environmental status of a material or product. The majority of studies are confined to the manufacturing process, but several projects recently presented and ongoing studies aimed to investigate on the entire life cycle. These studies are mostly directed to compare the environmental profile of the wooden product with an substitute which is, of course, one of the main issues of the LC approach.

In North America, most work regarding LCA of wood products has been done in Canada where Forintek provided a comprehensive report on environmentally related data for materials and products used as building components. In Canada as well as is the US, several wood product associations are preparing LC information to convince architects and decision makers that constructing with wood is the right choice, especially under ecological aspects.

Table 1. Processes and modules analyzed in LCA or related studies.

Module/product	Organization/ institute	Parameter studied	Range (P,CP,LC)
Timber harvesting	IWR, Univ. Munich 1994	Energy CO_2	P
	EMPA/BFK 1990	Energy Critical air volume	P
Lumber production	EMPA/BFK 1990	Energy Critical air volume	CP
	I W 1991	Energy, emissions, waste	CP
	BFH 1986	Energy	P
Gluelams	EMPA/BFK 1990	Energy Critical air volume	CP
	BFH 1986	Energy	P
	BFH/IWR 1993	Energy, CO_2	CP
Reconstituted boards	BFH 1986	Energy	P
	EMPA/BFK 1990	Energy Critical air volume	CP
	TNO 1994a	Energy	P
	EMPA 1995a	Energy, air, water, soil emissions	CP
Exterior walls	EMPA 1992	Energy, air, water, soil emissions	CP
	Traetek 1994	Energy, air, water, soil emissions	LCA
Window frames	CML 1990	Energy, water, air soil emissions	LCA
	EMPA 1992	Energy, air emissions	LCA
	OeKI 1994	Energy, water, air soil emissions	PC/LCA
Poles	SIWT 1992	Energy, air, water	LCA
	EMPA 1995b	Energy, air, water, soil emissions	LCA
Poles, sleepers	IC 1995	Energy, air, water, soil emissions	CP/LCA
Pallets, packaging materials	TNO, 1994b	Energy, air, water soil emissions	LCA
Flooring	VTT 1995	Energy	P

P = process; CP = cumulated process; LC = life cycle

Main results of LCA on wood products

- The first important advantage of wood compared to other materials is its renewability within a biologic ecosystem. However, this status is yet not documented enough by LCA, because the depletion of natural resources is difficult to estimate in a quantitative way for most fossil resources. On the other hand, this positive aspect of wood can only be quoted when proper forest management and timber harvesting practices are employed to ensure adequate raw material supply for the future demand. All of us know that this assumption can not be guaranteed in all regions of the world.

- The embodied energy of wood as a raw or basic material is substantially less than of potential substitute materials. However, this may change when a complete product is regarded. Here it is important to split up between energy - based on fossil energy carriers - and energy - based on renewable resources. By doing so, most wood-based products have benefits because thermal energy used in wood processing (esp. drying) is generated by wood waste fuels produced during processing.

- This aspect leads directly to the second and certainly most obvious benefit of wood products: the low contribution to the global warming which could be shown in many studies where CO_2 and other 'greenhouse gases' have been considered. This benefit of wood products could even be increased when the sink-effects of carbon in long-lasting timber products can be modeled and evaluated in LCA's, e.g. in form of negative credits for every years delay in emission release.

- The next evident benefit of wooden products is their relatively small waste volumes. Most wastes and wood-based materials can be burned after their service life. Only the ashes and filter particulates have to be deposited in special landfills. As a rule of thumb, the natural resource is used to nearly 95%. The ashes of used timber products, however, are in most cases contaminated by ancillary materials (paints, preservatives, adhesives, overlays), and should not be used as fertilizer in agriculture.

- Because wood as a biological resource owns a high variability in its inherent material properties, more maintenance and special treatments are necessary to guarantee a long-lasting service, especially when exposed outdoors . These treatments may affect the possibilities of a material reuse, which are given and promoted for most of the plastic and metal substitutes used in the building sector. In LCA's this can lead to some unexpected results when the future recycling potential of alternative materials is rated in an optimistic way.

- A subjective observation in environmental evaluation studies conducted so far is that modules analysed with more scrutiny and combined with better investigated basic data are being rated by more negative figures. Environmental improvements in processes can only be documented when the same evaluation methods and input data are used to assess an updated and not extended data inventory.

Strong points of LCA studies on wood products

- LCA have allowed to quantify the environmental benefits of wood products. This recently lead, at least in Continental Europe, to a slight increase in timber utilization in the building sector (timber framing, flooring, siding) because architects and builders are becoming more sensible towards environmental issues.

- By the calculation of a GWP the advantages of wood regarding the carbon ecology can be proved quantitatively.

- With better data of the so-called precombustion processes (impacts of the prospection, extraction of energy carriers and their transformation to energy), all materials and products based on fossil resources are rated by the adequate environmental burden, so that the relative benefits of wood-derived materials may become more obvious.

Weak points of LCA studies on wood products

- The positive role of forestry is not documented in an adequate way within LCA. Until now, timber alone carries the impacts of forest management. But all other intrinsic values with a direct profit on human beings and environment (scenic and recreational values, protection functions, wildlife habitat, water management, climate regulation, noise and dust filter) are co-products, which have to allocate a share of the negative impacts of forest management.

- The quality of the LCA data presented so far is difficult to estimate. Many studies do not provide a sufficient documentation about system boundaries and set up of the projects so that an valuation of the data as well as an comparison to other studies is nearly impossible.

- Although regional and geographical singularities should be expressed in LCA's, many of the processes in the forest products industry can be treated as site independent modules. Until now, only little coordination of activities took place on an international level. This should be improved in future. A data bank should be established and maintained by an international organization, where peer reviewed results of forest products related LCA data should be hold in trust for other scientists.

- Most LCA studies done so far in the forest industry sector are stimulated and carried out by governmentally funded research institutes and universities. The wood industries, in contrast, have shown only little initiative although they should have a main interest in those types of analysis. A closer cooperation between the research community and the industry is needed to come to better inventory data and to profit from the second potential of LCA, this is the discussion and realization of process improvements.

Summary and future research tasks

Life cycle modelling is a relatively new method. Despite many critics and still unresolved methodological questions, it is rapidly gaining acceptance as a reliable source of information if the background information necessary for an interpretation of the results is disclosed.

The main advantages of timber-derived products are their renewability from a natural resource and its benefits regarding the CO_2 ecology. These are so-called basic values, which can be credited independent from the use in specific products.

In many studies presented so far, wood as a raw material showed distinct advantages over alternative products. However, on a product's scale wood-components have to be rated in the same way as all other materials. The ecological profile of wooden products strongly depends on the degree of industrial transformation and the combination to other materials and ancillaries. In most cases, wooden composites are not 'per definition' reusable, recyclable and nontoxic. There is still a certain potential for ecological improvements in most manufacturing and fabrication lines. Additionally, end users should realize that they significantly can influence the environmental profile of a wooden product by periodical but benign maintenance activities.

The forestry-wood LC research community should:
- conduct future LCA's according to the guidelines of SETAC or ISO 14040ff
- give emphasis on the inventory analysis of single modules in the forest-wood chain, which are frequently needed for a further evaluation of products
- enable quantitative assessment of forest management by-products
- develop criteria for an adequate consideration of carbon-sink effects in timber

- discuss and agree on the most important modules and their intersections
- discuss and agree on guidelines for the allocation problems in the forest products industry
- improve international cooperation and information transfers
- establish an international peer-review group and a data-bank service for specific LCA data of forest and wood related modules
- investigate statistically the service life and maintenance interval of wooden products as input parameter in LCA's
- participate actively in the standardization process to guarantee that forest-wood specific properties are respected in general LCA guidelines.

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BUILDING MATERIALS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT: AN OVERVIEW OF FORINTEK'S RESEARCH PROGRAM AND MODEL

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Abstract

Four years ago Forintek Canada Corp. established a research alliance of private, public and academic institutions under the auspices of Natural Resources Canada to develop an analytical framework for life-cycle assessments of building materials. The ultimate objective of the research alliance was to develop a systems model that would allow the building community to assess the relative environmental implications of using various structural building materials in defined applications. ATHENA™ is a prototype software tool that generates a detailed life-cycle impact assessment of steel, wood and concrete building materials used in various building assemblies.

This paper provides an overview of the Alliance's life-cycle approach and will illustrate the output of ATHENA™ by way of an example comparing wood and steel in a wall application.

Introduction

As we have already heard, the wood products industry is facing some tremendous challenges on the environmental front and in the Life-Cycle Analysis arena.

Essentially, the environmental movement has changed the public's perception about how we manage forest resources and subsequently, how they view wood products. At the same time they have created a lot of uncertainty. As an industry we see this uncertainty manifest itself in higher wood product prices and more volatile price swings, which in turn, has opened the door to unprecedented possibilities for substituting alternative materials for wood.

I want to give you a brief overview of Forintek's LCA project. In the process I am going to introduce some concepts we need to understand so we can look at environmentally motivated substitution in an objective and constructive light. I'm also going to tie these concepts together as I discuss the research program and then, I am going to finish off by sharing with you some preliminary results generated via our model.

Product substitution criteria

Historically, product performance and price have been the primary drivers behind substitution of wood and non-wood products. I contend that government regulation, motivated by the environmental movement, will increasingly affect building material choices in the future. One result is likely to be the use of a wider mix of building products in any given structure as we begin to distinguish between each products environmental benefits and cost. Or in other words, competition between alternative building materials will be redefined to include environmental as well as traditional price and product performance criteria.

Unfortunately, the prevailing price system is incapable of accounting for the environment and may actually send perverse signals about the relative environmental benefits and costs associated with competing products, especially when they are made of different materials. Although in time we can expect to see more environmental factors embodied in the price system (such as carbon or energy type taxes) and therefore in the cost of building materials, the use of market forces to achieve environmental objectives is not likely to occur quickly or on a broad front. I will return to this price system a little later in the presentation.

Now the environmental cloud hanging over the wood products industry coupled with the recent price volatility of wood products and the stagnation of nonresidential construction markets in North America, has the steel and concrete industries doubling their efforts to capture a share of traditional wood markets.

Subsequently, each industry has begun to position themselves against the other as the obvious "green" choice with glossy brochures and marketing campaigns. Now the goal of the steel industry is to have a 25% share of the residential framing market before the turn of the century. While this is probably optimistic, just setting the target gives a pretty clear indication as to the direction they are heading.

So what we have here is a lot of environmental information being put out by all the material groups, each with their environmental claim to fame, which only tells a small part of the whole story. For instance, steel major environmental claim is that it is the most recycled material in North America, wood chooses to underscore its renewability trait and concrete counters with the claim of being produced locally from common and abundant natural resources.

And then we have the environmentalists who I think are rightfully concerned, but seem to be rather shortsighted. They have not yet considered that if timber is not to be a product of the forest than what do we replace timber with, and are these alternatives more or less environmentally benign.

Building materials in the context of sustainable development

The combination of a maturing environmental movement, the inefficiencies built into the market price system and the piecemeal measures we presently use to gauge product environmental impacts all provided the impetus for a project we initiated four years ago entitled *"Building Materials in the Context of Sustainable Development"*.

The concept of sustainable development links the common themes of maintaining, sustaining and preserving environmental processes and of dealing with environmental constraints when meeting present and future needs. Perhaps the number one problem that plagues the concept is that it is not a one time goal that can be precisely defined and then achieved in a certain period of time. Rather it is more like a moving target, because as our global population continues to grow, it puts additional pressures on our planets resources.

From our perspective, the concept's primary value is its broad scope and implied shift away from shortsighted and economically expedient decisions in favour of something of a more thoughtful and balanced orientation in the long-term.

The concept of sustainable development has captured the imagination of society as a whole. The business community, governments and the general public continue to be very interested in having a means to holistically examine and reduce the environmental impacts of products, processes and our daily activities.

As a society, we have well developed methods and criteria to measure productivity and profits to help us improve performance. That is, ways of thinking about, comparing and selecting from alternatives. The challenge is to develop a similar tool to incorporate sustainable development into our decision process. One tool is emerging on the international scene which seems to offer us a method for comparing environmental trade-offs in something more than in a piecemeal way. It has more than one name, but it is most commonly referred to as life-cycle analysis.

It is a process whereby the environmental burdens associated with a product, process or activity is evaluated by quantifying energy, material usage and environmental releases throughout the life-cycle. Because all products, processes and activities impose some toll on the environment, we have to asses these environmental impacts on a comparative or relative scale while at the same time striving to improve their individual environmental performance.

Life cycle analysis, while originally developed in the 1970's, is still undergoing refinement (and has slowly filtered down to the business unit level as a tool for allocating scarce resources among competing pollution abatement goals so industries can get the best bang for their pollution abatement buck.

The International Standards Organization (ISO) has also established a technical committee (TC207), headed by Canada, to harmonize life-cycle analysis around the world. It is believed that this methodology will form the cornerstone for environmental claims and environmental choice programs in the future.

While our project has a number of secondary objectives, the ultimate goal is to make available a simple model which will enable the building community to assess the relative environmental implications of using various building materials in defined applications: again within this holistic framework of sustainable development. The goal here is not to mount an all out offensive in favour of wood, but rather, to encourage the wider use of all materials in any particular building design such that together they minimize the building's environmental impact.

As I have already discussed, the sustainable development doctrine demands that we look at the environmental consequences of an area of activity such as building construction from a broad perspective (Figure 1). We think that our life-cycle approach is up to the task. It starts with the idea that five main activity stages define the life-cycle of a building. These include resource extraction, product manufacturing, on-site construction, building occupancy and maintenance and lastly, demolition and disposal of the building. Transportation services within and between these activity stages are also included.

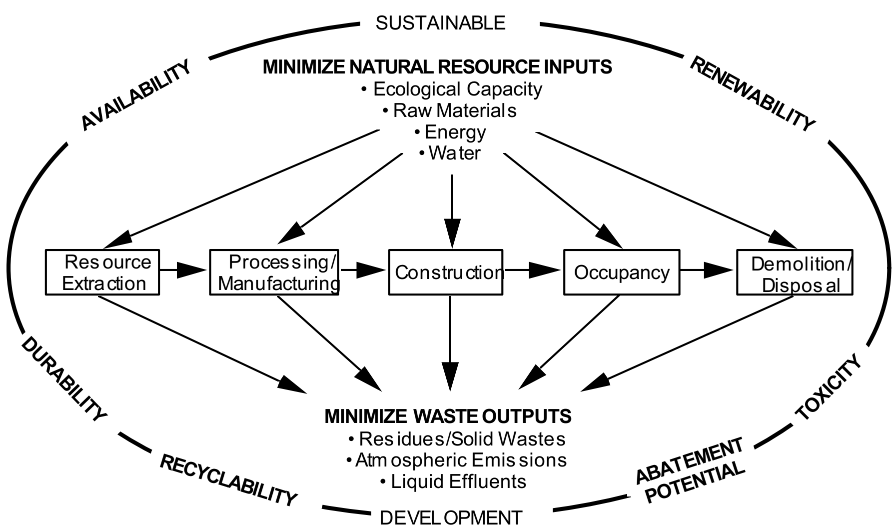

Figure 1. The sustainability of building construction: objectives and criteria.

What we are concerned with is how various building materials interact with and affect the environment during these five activity stages. And to this end we have defined the sustainable development objective to be the minimization of physical environmental inputs and outputs required over the life of the building.

We also have to consider these inputs and outputs in the context of various sustainable development criteria such as resource availability and renewability, product durability and recyclability as well as substance toxicity and pollution abatement levels.

The physical environmental inputs and outputs are relatively straightforward, with perhaps the exception of the term "ecological capacity". For our purposes, ecological capacity denotes the numerous other effects caused by human interaction with the physical environment during the extraction phase of the life-cycle. A major task of the project is to assess some of these key effects and incorporate them into our model. We have had some success in this regard (See the paper by Mr. W.B. Trusty).

One notable difference between a building LCA and the generic product LCA model is added complexity in terms of life cycle or activity stages to be studied in the inventory phase. If we think of the building as a product in its own right, then the entire process of manufacturing individual products and subassemblies is equivalent to material acquisition for the building. Building construction is then equivalent to manufacturing. As a result, we have an additional activity stage in our framework compared to the generic LCA framework.

A project of this scope of course demands numerous skill-sets (Figure 2). So over a period of six months we established a multi-disciplinary research alliance of eight organizations comprised of three university programs, three private consulting firms, a government agency and Forintek to undertake this multifaceted project.

We have gone to great lengths to structure the alliance such that the objectivity and integrity of the study is not compromised. Over the last 24 months the research alliance has completed the major analytical task. The focus of this work has been on vertical and horizontal structural assemblies using a number of wood, steel and concrete products in light commercial and residential buildings.

Canada Centre for Mineral and Energy Technology

Centre for Studies in Construction,
University of Western Ontario

Environmental Policy Research at Trent University

Environmental Research Group, School of Architecture
University of British Columbia

Forintek Canada Corp

Hatch Associates Ltd.

JKM Associates

W. B. Trusty and Associates Ltd.

Figure 2. Research alliance.

INPUTS

• Energy Use • Water Demand • Resource Use

OUTPUTS

• Air Emissions • Liquid Effluent • Solid Wastes

Figure 3. Inventory data elements.

So far we have developed what we call life-cycle inventory data (Figure 3) for a number of these products in terms of their raw material requirements, embodied energy, the demand they place on the water supply, solid wastes produced and a select number of atmospheric emissions and liquid effluent; from the resource extraction stage to completion of a structural assembly on a construction site. An example of a unit factor estimate would be GJ of energy used per tonne of steel or KG of CO_2 emitted per MBM of lumber.

In essence, the alliance's research to-date has advanced our environmental understanding on three fronts:

First, we have provided a new standardized benchmark for environmental assessment of building materials. So, no longer do we need to use dated information from a number of different sources employing different research methodologies;

Second, we have expanded the number of environmental variables considered beyond energy use and atmospheric emissions; and,

Lastly, we've moved the analysis forward by explicitly considering the construction activity stage.

The model: an impact assessment tool

We also have a prototype version of our computer model up and running, which we call Athena (Figure 4). It contains a menu of typical floor, roof and wall assemblies for the three materials from which the user specifies the building's geographical location, the actual space to be modeled and the working loads and spans. The model proceeds to determine and then breaks down the required assemblies into their respective materials and applies our LCI data to the materials used. At the same time it calculates the primary energy used in the electrity grid and in the precombustion energy associated with the production and delivery of the fossil fuels consumed by each material. It then compiles the total environmental inputs

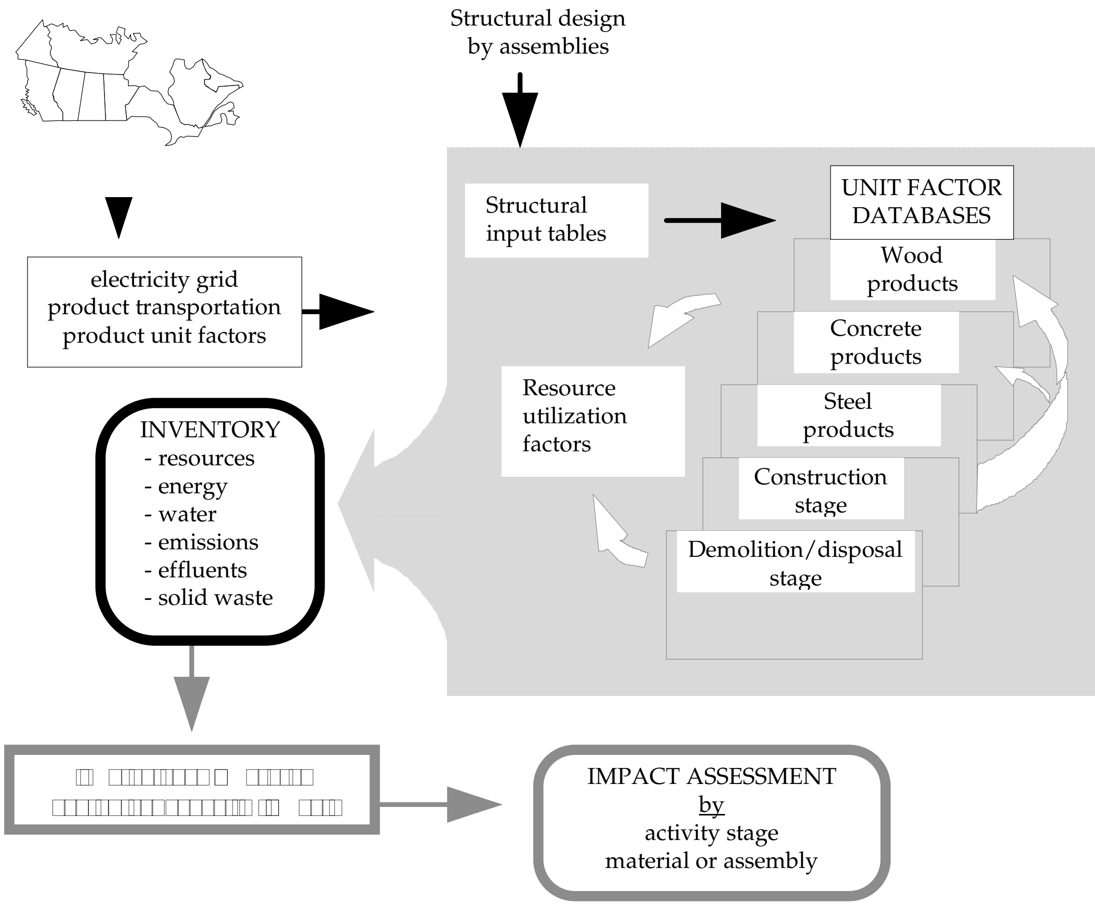

Figure 4. ATHENA™ Model Schematic.

and outputs for that particular design. The real value of the model is that it allows the building designer to focus in on what aspects of the design are particularly environmentally costly and then try alternative materials and assemblies and materials to reduce the buildings environmental load or cost.

The model focuses on comparative building assembly designs rather than on comparing materials directly. This focus is necessary because unit measures such as a pound of wood versus a pound of steel or concrete is for all practical purposes meaningless as such measures do not consider the functional capability of each of the materials in use.

Essentially, the model is an impact assessment tool. Within in which, the inputs and outputs are the environmental impact indicators. But we have also developed additional impact assessment indicators to explicitly consider ecological capacity effects of resource extraction and equivalence measures of the hazard posed by air and water emissions. We have developed these additional classification indexes to help model users in the interpretation of the environmental inputs and outputs.

Equivalence Factors CO_2 = 1.0

The greenhouse gas index (GGI) reflects equivalent CO_2 kg

Greenhouse gas	20Yr. Horizon greenhouse gas CO_2 equivalence	100Yr. Horizon greenhouse gas CO_2 equivalence
CO_2	1	1
CO	3	2
NO_x	150	40
CH_4	63	21

$$GGI\ (kg) = CO_2kg + \frac{(COg \times 3 + NO_xg \times 150 + CH_4g \times 63)}{1000}$$

Figure 5. Greenhouse gas impact index.

The first of these equivalence measures deals with greenhouse gases (Figure 5). Here we equate the heat trapping capability of a number of gases with that of CO_2, which is referred to as CO_2 equivalence effect. This effect has a time factor due to the atmospheric reactivity or stability of the gas over time. Our greenhouse gas index is based on the 20 year time horizon effect and is a result of weighting the absolute output of these gases by their relative effect and combining them into one index.

Also Equivalence Based:

- inventory data for atmospheric emissions and liquid effluents are reduced to single indicies using relative environmental impact factors

API = $SO_2/.03 + SPM/.06 + CO/6.0 + NO_2/.06 + VOC/6.0 + Phen/2.0$

WPI = $TDS/5.0 + PAH/.1x10^{-6} + Non\text{-}Ferr/.003 + CN/.5x10^{-4} + Phen/.1x10^{-4} + Nitr\text{-}Ammn/.02 + HalgOrg/.0002 + Chlor/2.5 + Alum/.001 + Oil.Gr./.01 + Sulphate/5.0 + Sulphide/.0005 + Iron/.003$

- API and WPI estimate the total volume of ambiant air or water necessary to dilute all releases to within recommended levels

Figure 6. ***Air and water pollution impact indicies.***

The air and water pollution indexes use the relative toxicity of emissions as weighting factors (Figure 6). The concentration levels are typically the legislated limit which will prevent adverse effects on ecosystems and human health. While the indexes appear additive, we actually only use and report the worse offender - that is, the largest single volume of air or water required to dilute the worse element to acceptable levels. We do this because each cubic metre of air or water can contain a number of pollutants, so in the process of calculating the worse offender we also dilute all other emissions to acceptable levels.

Some model results

To illustrate some of these measures, I now want to run through an actual assembly comparison using our model and data for two materials in a simple application. The application for comparison is a typical exterior infill wall assembly used in light commercial structures. Usually a building this type of assembly would be built using steel as the post and beam supporting structure.

For the purpose of material comparison, we used 20 ga. steel studs (C cross-section, about 1mm thick) as one example, and 2x4 (38x89mm) wood studs as the second alternative. The infill space to be modeled was arbitrarily set at 3 meters high by 30 meters long.

Figure 7 summarizes the virgin resource demands for the two alternative wall infill methods. It took about 600 kg of raw materials to produce the softwood lumber and nails used to in the wood wall assembly. So on a virgin mass basis, the wood design is only 75% as resources intensive as the steel design.

Resource	Wood Design	Steel Design
Limestone	-	77
Iron Ore	-	508
Coal	-	251
Wood Fibre	598	-
Total	598	836

Figure 7. ***Raw resource use (kg)* - 3m x 30m wall example (*excludes recycled scrap).***

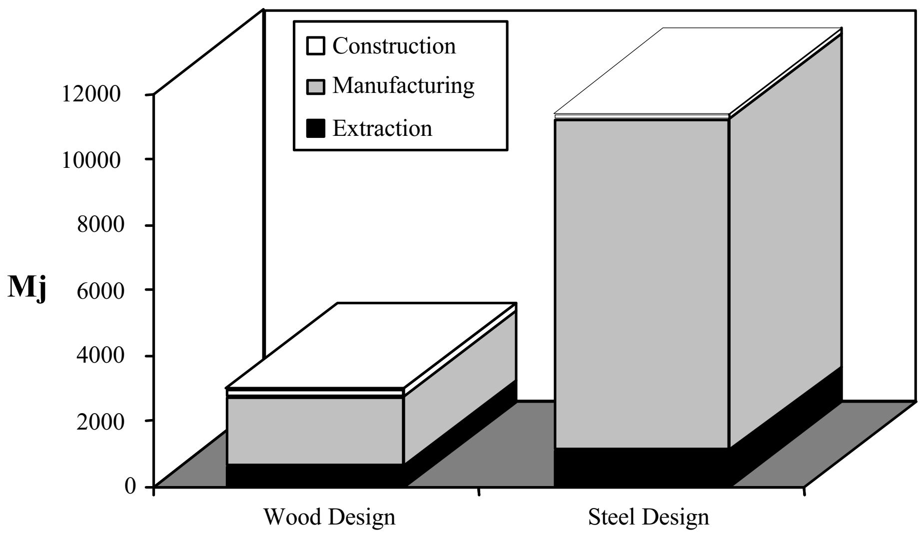

Figure 8. ***Energy use (Mj) 3m x 30m wall example.***

In terms of embodied energy (Figure 8), the steel wall is 3.5 times more energy intensive than the comparable wood wall. The steel wall is more energy intensive in terms of resource extraction and manufacturing, but is slightly less energy intensive than wood during the actual process of construction.

Now minimizing energy use is a key sustainable development objective as energy, especially energy from fossil fuels, represents a major environmental impact. Moreover, as builders and architects strive to make their buildings more energy efficient, the embodied energy of the building materials used becomes more significant. In Canada, energy efficient residential designs relative conventional designs are twice as energy efficient and subsequently, embodied energy of the materials expressed as years of operating energy has grown two-fold in importance as well. We think this energy efficiency trend is going to continue unabated and may even accelerate in the near future. Hence, the wise choice of materials from the outset should be a major concern.

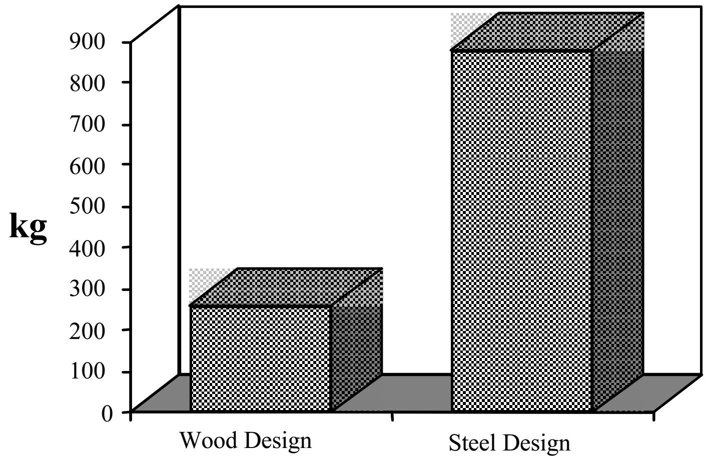

Figure 9. Carbon dioxide emissions (kg).

All human endeavor results in a host of atmospheric emissions, some of which are more serious than others. One emission that is especially topical and perhaps even critical is carbon dioxide, because of its role in global warming. Carbon dioxide emissions for the steel wall are three times that of the wood wall (Figure 9). The relative energy intensiveness of the two products explains a large portion of the carbon dioxide emission difference.

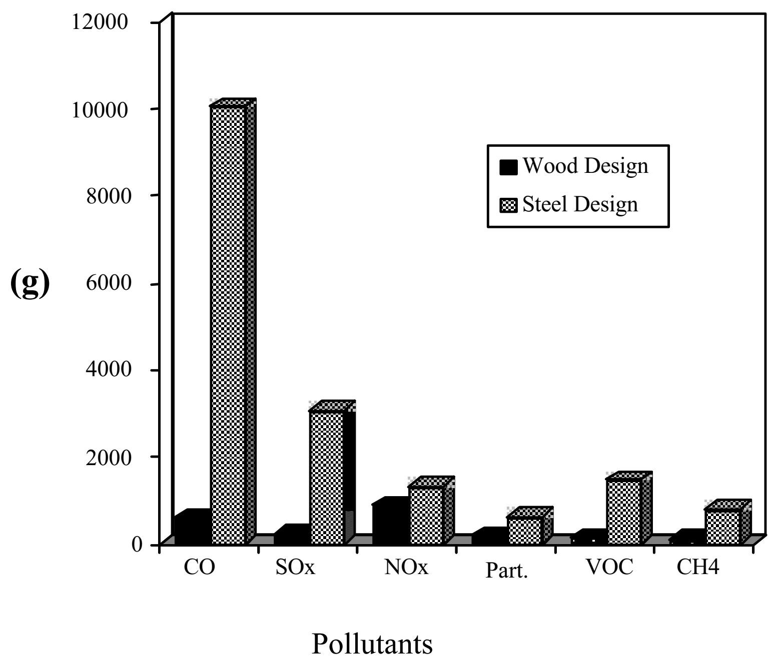

Figure 10. Other air emissions (g).

Figure 10 provides further comparison for some other important emissions. Here again, the wood assembly proves advantageous when we compare carbon monoxide, sulpher dioxide, nitrous oxides, methane, particulates and volatile organic compound emissions; all of which pose a hazard either to human health or the environment.

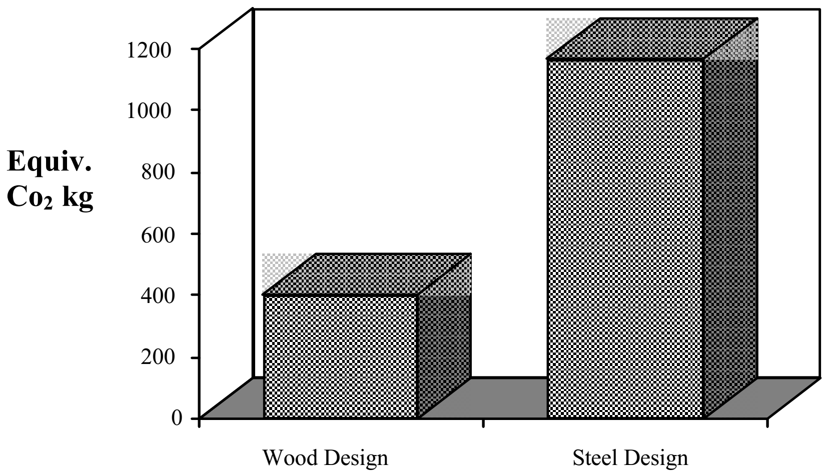

Figure 11. Greenhouse gas impact.

In terms of the greenhouse effect (Figure 11), the wood wall generates only a third of the effect of the steel wall. Carbon dioxide and nitrous oxides being the largest contributors to this effect.

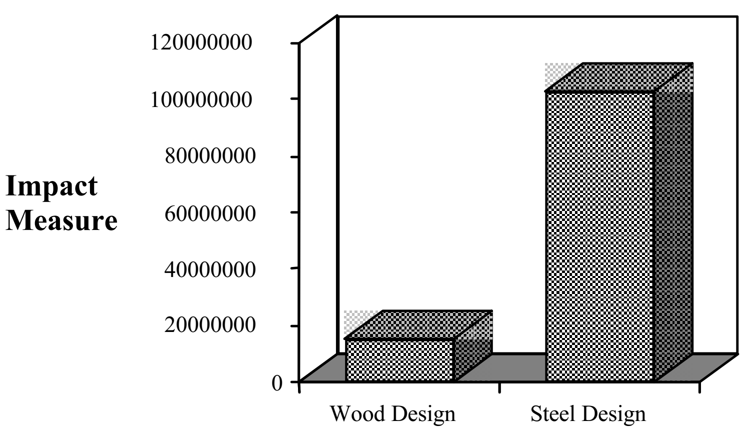

Figure 12. Air pollution impact.

The calculated Air Pollution Impact (Figure 12) indicates that relative to the wood wall, the steel wall requires seven times the volume of ambient air to dissipate its air pollutants to acceptable levels.

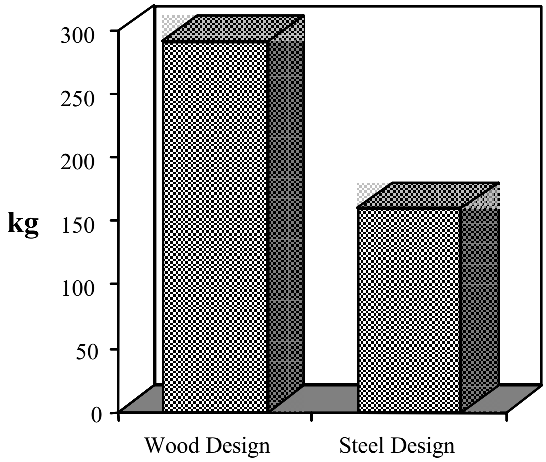

Figure 13.   Solid waste (kg).

Another consideration is solid waste (Figure 13). The solid waste generated during manufacture and construction was about 30kg higher for the wood wall. This outcome is primarily due to the more efficient use of steel on the construction site. Wood has traditionally been inexpensive in N. America and hence a lot waste was generated due to inefficient use. However, because wood is now more expensive we expect to see on-site waste go down and these numbers to be more in line with each other.

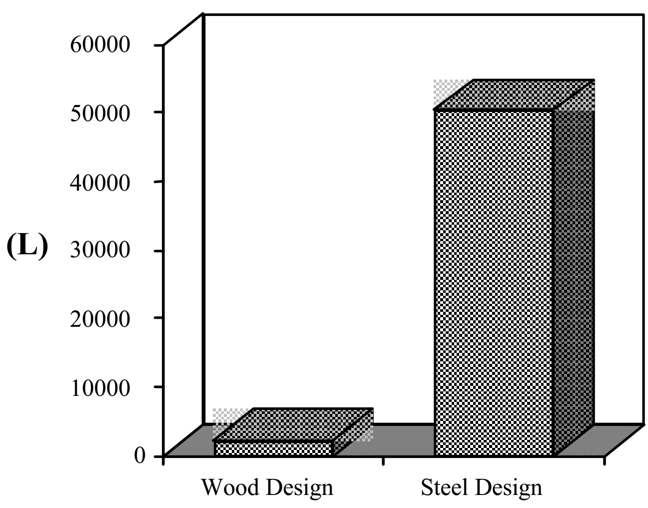

Figure 14.   Water demand (l).

The largest difference between the two material wall designs (Figure14) was found in their comparative water use during product manufacturing, with the steel assembly demanding over 20 times more water input relative to the wood design.

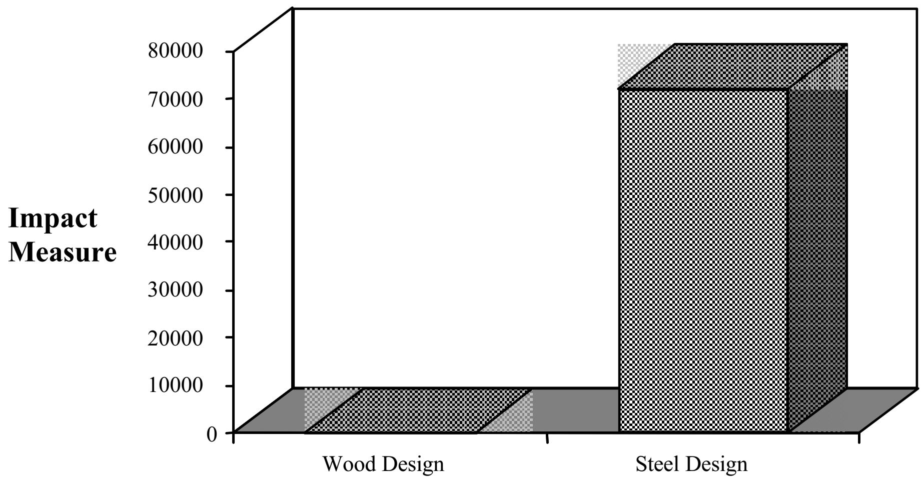

Figure 15. Water pollution impact.

Water use of course results in effluents. Figure 15 shows the calculated Water pollution index for the two walls. As is evident the amount of water necessary to dilute the effluent stream from the steel wall is considerably greater than for the wood wall.

That's the extent of our preliminary results to-date. As I mentioned, we still have a lot of work to do to complete the total picture. What you should take away from these preliminary results is that choosing between materials is by no means a simple task or in other words there is no SANTA - Simple Alternatives are Not The Answer.

Over the next three years our goal is to add the products necessary to fully enclose the structure and then include the operating energy of the building in the model.

STFI IN SEARCH OF AN AUTHORITATIVE DATABASE WITH AN ADAPTABLE STRUCTURE FOR FOREST PRODUCTS LCA

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Rolf Lindstr m & Anne Marie Vass, STFI
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Abstract

The Swedish forest products industry has asked STFI* to build up the necessary competence and capacity to carry out life-cycle analyses of the forest products industry's activities. The main goal of the work at STFI is to compile a forest products database for life-cycle inventory analyses covering all stages from raw material to finished product. The database, which includes Swedish annual average values, is built up in blocks divided into resource consumption and emissions. It is possible to continuously update the stored data and compile new information. In parallel an inter-Nordic project has been carried out in which criteria have been worked out for the collection and treatment of data for the inventory part of a life-cycle assessment.

"From cradle to grave" - from raw materials extraction to disposal

Life-cycle assessment has become a popular tool to describe a product from an environmental point of view. The concept dates back to the 1960s and 1970s in the USA. One of the problems was the growing mountain of garbage. Packagings of all kinds came under fire. On the one hand, they increased in quantity following an increasing goods flow and, on the other hand, they constituted a considerable proportion of the garbage mountain. It was realized that a correct and objective analysis concerning resource consumption and environmental impact must embrace all steps "from cradle to grave", i.e. from the raw materials extraction to their disposal.

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Need for coordination

Several studies were started to develop models and a way of describing the field. Such activities were also started in Europe. At first, these analyses were based on energy and material flows and available data concerning discharges, which were summarized without taking into consideration the type of discharge. It was not then of interest to make any evaluation of the environmental impact of the discharges. A couple of decades ago, knowledge in the field of environmental impacts was very limited compared with the situation today.

While the methodology for life-cycle assessments was being developed, a number of difficulties in the method were discovered. From the beginning, the methods were considered to be objective instruments, but they were later shown to be based on a number of questionable considerations. Deficiencies and errors were also evident in the data used in several studies.

Individual companies within the pulp and paper industry are often asked about their resource consumption and specific discharges etc. They often find it difficult to foresee the context in which the information is to be used, and afterwards to question general statements from life-cycle assessments. There is a great risk that single values are given a general validity regardless of whether or not they are representative of the industry as a whole.

In spite of the reported deficiencies, life-cycle assessments have come to be used in marketing and also by national and local authorities, especially on the European continent, which is an important market for Swedish products. As a consequence, a clear demand has arisen for a coordinating function to be established at STFI to deal with life-cycle inventory analysis questions and in particular to set up a representative database.

Broad competence is required

A life-cycle assessment includes several components:
- Inventory analysis
- Classification (type of environmental impact)
- Evaluation of environmental impact

In order to carry out life-cycle assessments relating to pulp and paper products, competence is required in a number of different fields. A broad and deep knowledge of process technology is a condition for the collection of data. This involves not only technical knowledge about the manufacture of the studied product but also knowledge about e.g. the manufacture of chemicals used in the process.

Energy and environmental questions are central to any life-cycle assessment, and competence in both organic and inorganic chemistry is therefore a necessity.

Since the technical and chemical parts of a life-cycle assessment are to be related to environmental effects, knowledge is also required within the biological, toxicological and ecological sciences.

STFI's database

The Swedish forest products industry has asked STFI to build up the necessary competence and capacity to carry out life-cycle inventory analyses of the forest products industry's activities with the aim of supporting the industry, both as a collective branch and, if required, at the individual company level. A group of representatives from the forest products industry with a strong involvement in the life-cycle assessment field within Sweden and internationally is providing support for the work.

The main goal of the activity is to compile a forest products database for life-cycle inventory analyses covering all stages from raw material to finished product. The data stored in the database must be representative of Swedish products and conditions and it must be possible to use the database to obtain objective and correct information for use in its external contacts.

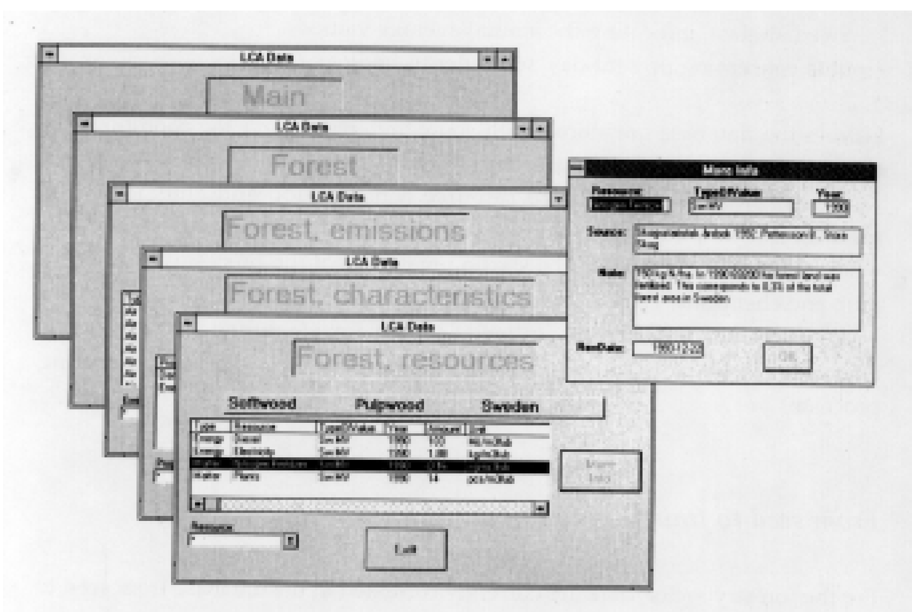

Figure 1. ***The database is built up in Microsoft Access for use on a PC.***

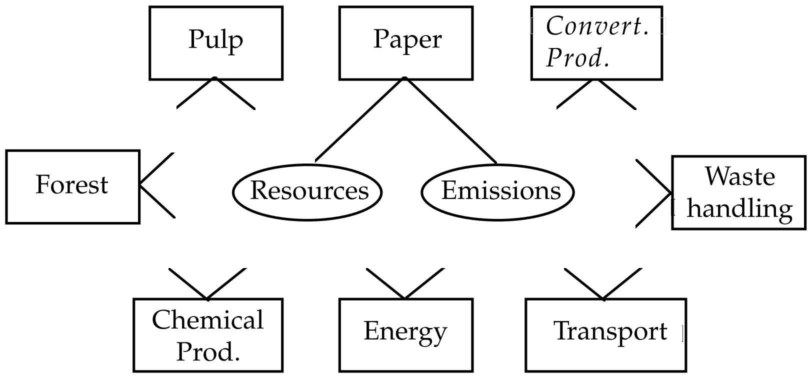

Figure 2. The database is built up in blocks including all stages from raw materials extraction to disposal ("from cradle to grave") for the products from the pulp and paper industry. All the text is written in English.

The database is built up in blocks. The work has begun with the forest including silviculture and harvesting of wood followed by the pulp mill, the paper mill (nonintegrated and integrated) and converting. Besides these blocks, data relating to energy production, chemicals, transport and waste handling are also included. The database is written in English and includes:

- Swedish data, indicating the annual average values
- data concerning present-day and older technology (1980s).

Data in the database are stored with source references and the conditions for calculated values are presented. In the long term, foreign data will also be stored.

Each block is divided into resource consumption and emissions. The resource consumption includes raw materials, energy, fresh water and land use, where the raw materials are the starting materials of the processes, e.g. wood, pulp and chemicals. The emissions include discharges to air and water and solid waste. In the database, the absorption of carbon dioxide during forest growth is also considered as is the outflow of by-products from the manufacturing processes.

From seed to finished product

For the forestry sector, data are currently compiled in the database from seed to cut timber. Swedish average values for pine, spruce and birch are represented. A subdivision relating to different parts of the country has also been made for certain parameters.

For pulp and paper production, we are currently engaged in the task of obtaining Swedish average values for different types of products. Differences in quality and function of a given type of product (e.g. different proportions of recycled fibre) will be taken into account in the data treatment. At present, data for TMP (thermomechanical pulp), newsprint, kraft pulp, sack paper and liner are available. Data for CTMP, tissue, board, liquid board and chemicals are being processed. For paper production, data for pulp production and paper production are being separated wherever possible. For the production of chemicals, energy consumption and emissions must be compiled covering all stages from raw materials extraction to the final product.

Nordic cooperation

An inter-Nordic one-year project has been carried out, financed partly by the Nordic Industrial Fund within the framework of the so-called NordPap-program. Experts from STFI in Stockholm, KCL in Helsinki, PFI in Oslo and Chalmers Industriteknik in Gothenburg have participated. In the project, criteria were worked out for the collection and treatment of data for the inventory part of a life-cycle assessment (Strömberg, 1995).

The work has been divided into four parts: system boundaries, parameter choice, units and data quality, where the last three can be said to be interconnected.

A uniform description of system boundaries for partial and total processes is a condition for making correct comparisons between different products. In establishing system boundaries, allocation questions were also treated. This means that criteria are proposed for how raw materials, energy and emissions shall be distributed when several products are manufactured in the same unit.

Other fields were also treated under the heading of system boundaries, e.g. process and additive chemicals and energy production.

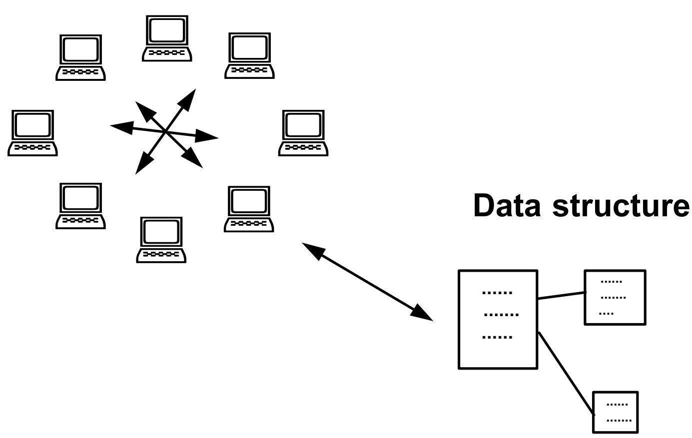

Figure 3. The development of national and international LCA database networks is dependent of commonly accepted data structures.

In any life-cycle inventory analysis, a large number of parameters must be considered. In a database for forest products, a choice of parameters must be made, based on what authorities, industry, research groups and others working with life-cycle analyses consider to be relevant.

In order to facilitate the understanding of and to make it possible to compare results from life-cycle inventory analyses, it is important that data are reported in the same units. A common list of parameters and units is presented.

The information which can be found in a database must meet certain quality requirements in order to permit credible analyses to be carried out. Work is being carried out within several organizations to determine criteria for data quality. It is necessary that databases for life-cycle assessments within the forest products industry are built to internationally accepted quality standards. Data quality means among other things that the source of the information is available, that consideration is given to the age of the information, that the measurement method (preferable standardized) is indicated and that data have been processed in a correct way.

The results of the project have found an immediate use in the building-up of STFI's database.

The information in STFI's database will be valuable in national and international contexts whenever life-cycle analyses of cellulose-based materials are discussed.

STFI, SkogForsk and Trätek have recently started a cooperation project regarding the development of an LCI database network for the products from the forest and wood products industries. Each institute will have its own database, but data can easily be transferred between the databases.

LCA and LCI databases are also developed in other Nordic Industry branches. A common Nordic database structure is currently tested out. The content of STFIs LCA database can easily be adapted to this database structure.

There are also other projects going on regarding the harmonization of data structures. All those activities show that we can expect a future with the existence of one or more international networks of local or national LCA-databases. Such networks will be valuable tools in our future work on LCA.

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DISPOSAL OF CCA TREATED WASTE WOOD BY COMBUSTION

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Technical Research Centre of Finland

Abstract

Totally 272 m^3 (62.7 t) of CCA treated wood was chipped and incinerated at Jalasjärvi Gasification Plant. On average the whole batch of chips contained 57 kg copper, 95 kg chromium and 76 kg arsenic. During the 56 h combustion trial the measured arsenic emission to the air was 76 g in total. Copper and chromium emissions were less than 1 g. The results were used for LCA of copper, chrome and arsenic treated utility poles.

Introduction

In recent years the recycling of treated timber is gaining more and more attention. With increasing production of treated timber we sooner or later come to the situation that treated timber reaches the end of its service life.

The most natural way of recycling treated timber is to reuse it, perhaps as a component or as a part of another construction. As an example, transmission poles and railway sleepers can be used for landscaping. However, this is not always possible for several reasons.

Recently recycling research has provided several alternative methods. Biological method (Stephan, Peek, 1992) to detoxify wood treated with salt preservatives has been studied In Hamburg. Also chemical extraction methods (Honda, Kanjo, Kimoto, Koshii, Kashiwazaki, 1991) and (Pasek, McIntyre, 1993), including both acidic and ammoniacal routes have been examined. The latter work also investigates burning of CCA treated wood showing no loss of copper or chromium and only minor loss of arsenic according to laboratory experiments.

Further combustion experiments have shown only very little differences in combustion products and oxygen uptake between untreated and treated timber. Also extraction methods to remove metals from remaining ash has been studied (Cornfield, Vollam, Fardell, 1993).

Outokumpu Oy is a large Finnish company. The corporation operates all over the world and its business segments are Base Metals Production, Copper

Products, Stainless Steel and Technology. The segments are divided to business sectors which cover areas from mining to refining metals and other technologies. The production plants of Outokumpu Harjavalta Metals Oy are situated in southwest of Finland. A part of its production line is refining copper concentrates to copper by flash smelting process. The CCA production is combined to this process.

Since 1986 Outokumpu started to collect small amounts of copper-, chrome- and arsenic-containing sludges and other hazardous wastes from domestic treatment plant customers. Wastes, typically containing heavy metals and organic materials, are fed to the copper smelter and recycled by this way. The operation was accepted by the local authorities. Typical analysis of sludge shows from 1 to 15 % of copper, arsenic, chromium and iron.

In 1986, 10 tons of hazardous wastes were treated and then irregularly smaller amounts. Wastes have been transported also from Sweden. This service has been offered to the Nordic customers free of charge. Earlier wastes were simply stored on the plant yard or transported to an expensive waste treatment plant. During these years no interference have been detected in Outokumpu's copper smelting line by recycling wastes.

A preliminary small scale trial to recycle CCA treated timber was carried out in September in 1993. Old electricity poles taken out of service were chipped by an ordinary heavy duty wood chipper. As a result some 20 m^3 (4.5 tons) of treated wood chips were collected and transported to Outokumpu's factory.

The whole batch was fed to the flash smelting furnace, where it smelted in oxygen rich atmosphere and in high temperature. Released energy from wood was utilized by the process, the burning gases were led to the sulphuric acid production and copper was utilized in the copper production. Residual arsenic and some residual copper were used in the manufacturing of CCA.

Large scale combustion trial

A new trial was planned to investigate heavy metal emissions during the combustion and further the treatment of remaining ash at Outokumpu's copper production plant. The results were also used in Life Cycle Assessment of CCA treated utility poles.

Jalasjärvi gasification heating plant was chosen to carry out the trial. The gasification heating plant is a system in which a solid fuel is first gasified in its entirety and the combustion gas produced is burned in the boiler. The plant can use any solid fuel but at Jalasjärvi peat and chipped wood are used as fuel. The plant has a maximum capacity of 7 MW and it is used as a district heating plant. This type of plant is environmentally friendly. The dust content of the flue gases has been found to vary from 40 to 250 mg/m^3. Also the proportions of PAHs in the fumes are low. The operating diagram of the plant is shown in Appendix 1.

CCA treated utility poles were chipped and then transported to the plant. Totally 196 m^3 of treated chips (46.6 t) were burned at plant. The trial lasted 56 h. Samples were collected from several stages of the process. Heavy metals, arsenic, chromium and copper, were measured in flue, in water condensate and finally in remaining ash.

Results

<u>Wooden chips</u>

Wooden chips were analyzed for copper, chrome and arsenic content. The average figures were following:

Table 1. The average content of As, Cu and Cr in chips.

Element	Content (%)	Calculated total content in the fuel (kg)
Arsenic	0.24	76
Copper	0.18	57
Chromium	0.30	95

<u>Metallic emission to the air</u>

Metallic contents were measured in the flue on the top of the pipe. Both particles and gaseous phases were measured.

Table 2. The total metallic emissions to the air during the 56 h trial.

Element	Emission (mg/h); min/max	Calculated total emission (g); min/max
Arsenic	1120 / 1640	63 / 92
Copper	13.6 / 20.2	0.8 / 1.1
Chromium	3.9 / 5.0	0.2 / 0.3

Also Co_x, SO_2 and NO contents were measured but results are not relevant in this study.

<u>Metallic contents in the water condensate</u>

All the water condensates from the flue gas cooling system (totally 21.8 m^3) and from the drop separator on the top of the pipe (totally 0.1 m^3) were collected and then analyzed.

Table 3. The content of As, Cu and Cr in cooling water condensate.

Element	Content (mg/l)	Calculated total content (kg)
Arsenic	650	14.2
Copper	0.3	0.007
Chromium	0.3	0.007

Table 4. The content of As, Cu and Cr in water from the drop separator.

Element	Content (mg/l)	Calculated total content (g)
Arsenic	300	30
Copper	3	0.3
Chromium	0.05	0.005

Both condensates were transported to Outokumpu's CCA production plant and utilized by the manufacturing process.

Analyzed amount of arsenic, copper and chromium in the ash

Ash was collected up to two weeks after the trial. Total amount of 8820 kg was removed to Outokumpu's copper refinery plant and treated through the process. The average analysis results are given in the Table 5.

Table 5. The average analysis results of CCA components in the ash.

Element	Content (%)	Calculated total content (kg)
Arsenic	0.1	8.8
Copper	0.38	34
Chromium	0.45	40

Discussion

The trial showed clearly that gasification type incinerator plant is environmentally a very good solution to dispose CCA treated wood wastes. The metallic emissions in the flue were exceptionally low during the combustion. The maximum measured arsenic emission was only 1.64 g/h leading to total emission of 92g during the 56 h combustion. This amount was only 0.1 % of the original total arsenic content in the flakes. However, no measurements were carried out when the wooden chips were changed again to peat. It is quite obvious that remaining arsenic in the plant continued to emit to the air with slowly decreasing tendency. Also this theory is supported by the fact that less than 30 % of the original arsenic was found by analysis in the condensates and in the ash. For copper the figure was 60 % and for chromium 42 %.

There were some inaccuracies in the analysis of ash too. Because of its very large volume (8820 kg) it was impossible to mix the ash before sampling. The ash was collected in small batches and the final batch was taken out two weeks after the trial. Obviously there still were remaining metallic components in the plant.

Conclusions

As a conclusion, gasification type combustion is a safe and environmentally friendly way to dispose CCA treated wood waste. To minimize the pollution it would be sensible to burn treated timber just before the annual maintenance work of the plant when the whole system is cleaned. This ensures that all the remaining arsenic, copper and chromium in the system can be removed safely.

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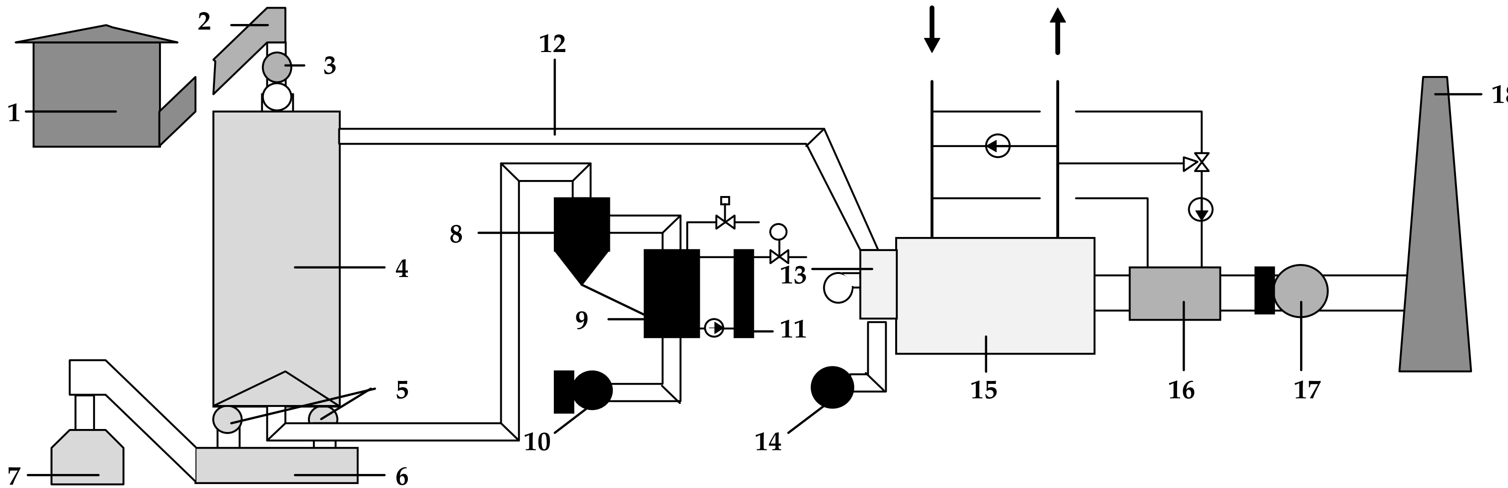
Annex 1. ***Bioneer boiler plant.***



1. Fuel bin
2. Fuel feed conveyor
3. Fuel feeder
4. Gas generator
5. Ash removers
6.
7. Ash pallette
8. Drop separator
9. Humidifier
10. Gasification air fan
11. Plate heat exchanger
12.
13. Gas burner
14. Combustion air fan
15. Gas boiler
16. Economizer
17. Flue gas fan

LCA Related to Pulp and Paper Products

ECO-BALANCES IN THE PULP INDUSTRY: ASSESSMENT OF ENVIRONMENTAL IMPACTS

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Abstract

The paper summarizes some attempts to assess the environmental compatibility of the pulp and viscose fiber production site at Lenzing, Upper Austria. The first part describes the mass flow and energy balances, referring also to some difficulties resulting from poorly defined output streams. The main part deals with the environmental impact assessment. After a short comparison of some different concepts, the method which we have used to evaluate our emissions is described. The method is called "Quality-Goal Relationships Concept" and uses long-term ambient concentrations (limit values) to relate the environmental impacts of various emissions to one another. Based on these relationships the so-called "Environmental Impact Added" (in analogy to value added) can be calculated.

Introduction

Lenzing AG is the world´s largest viscose fibre producer with production facilities in Europe, USA and Indonesia.

With a production capacity of ca. 132.000 tons/a (1994), the plant at Lenzing/ Upper Austria is the largest of the three facilities and the only one, which is fully integrated (i.e. the pulp is produced within the same production site as the viscose fibres). The pulp mill has a slightly higher capacity (138.000 t/a), the excess not being used for the fibre production is sold on the market. Besides, at the location in Lenzing there are produced:

- ca. 62.000 t/a of paper
- ca. 300 t/a of lyocell fibres (pilot-plant)
- synthetic films and
- plastics machinery.

The production site is characterized by a very small receiving river (Q_{95} ca. 7 m^3/s) and the vicinity of the Salzkammergut, one of the most famous touristic areas in

Austria. As a consequence, the company had to begin to set environmental measures at a comparatively early point and has now got leadership in environmental matters within its branch of industry.

Environmental assessment - LCA, eco-balance

Although complete LCAs (Life Cycle Assessments) of our products - especially with the view to an ecologically evaluated comparison between viscose fibres, cotton and some man-made fibres - were of special interest for our company, we put the emphasis of our efforts predominantly on the ecological valuation of the production site in Lenzing, Upper Austria. The main reasons for this decision were:

- First of all, the company has been undertaking a lot of measures to make the production site in Lenzing more compatible with the environment. During the last 15 years, both the aquatic and the gaseous emissions have been reduced to a reasonable extent.
- It is nearly impossible to make a complete LCA for viscose fibres. On one hand, you can assume that the post-production stages are nearly identical for different types of fibres, so you could neglect them - thereby overlooking one of the major advantages of cellulosic fibres, i.e. their biological degradability. On the other hand, the pre-production stages are almost impossible to valuate - to give you one example: for the production of viscose fibres you need NaOH; NaOH is produced by electrolysis of NaCl, thus being directly connected with the chlorine chemistry. Is it therefore necessary to include all of the problems resulting from the use of chlorine in the LCA of viscose fibres, where the use of chlorinated chemicals has been reduced almost completely? And, if yes, which types of chlorinated products should be valuated, because there is a big difference in the ecological behaviour of e.g. CCl_4 and PVC when used for windows or sanitary pipes?
- No methods are known so far, which are generally accepted and allow an objective valuation of the environmental impacts of products from different geographic regions. As a consequence you had to apply the same environmental standards for the production of cotton as well as for viscose fibres. But is it justified to apply the same limit values as we are used to in Europe for e.g. pesticides in Asian countries?

Eco-balance - definition

According to Braunschweig & Müller-Wenk (1993), an eco-balance is an ecologically valuated mass flow and energy balance. In spite of its brevity, the definition hits the nail on the head, especially as it includes the ecological assessment.

Nevertheless, a whole lot of definitions does exist and nearly everyone concerned with the matter has a different view of things and is expecting something different. For this reason, we call our attempts "environmental balance" instead of "eco-balance".

Mass flow and energy balances

Mass flow and energy balances build the fundament of any eco-balance. The better the balances, the better is also the result of the environmental valuation. Establishing the mass flow and energy balances is totally independent from the ecological assessment. This makes you free in the choice of the assessment model, and you can make use of any model you believe to be the best one.

For the environmental balance of our company we concentrated on the pulp, viscose fibres and paper productions. For practical reasons we divided them further into 8 modules, which were then treated as "black boxes" with their own in- and outputs. The following modules have been examined:

- pulp production with the modules evaporation, evaporator condensate extraction and the pulp production itself,
- viscose fibre production with the modules fibre production and chemicals recovery (predominantly from waste gas streams),
- paper production,
- energy production (no distinction has yet been made between renewable and fossile energy sources), and
- wastewater treatment.

<u>Input:</u>	Raw material Ancillary material Recycled/downcycled material Product streams (from other modules) to be treated (incl. downstream processing) Steam Electric power
<u>Output:</u>	Products By-products Recycled/downcycled material Product streams to other modules (incl. those to be treated in downstream processes) Emissions Steam Electric power

These groups have been further divided - e.g. into aquatic or gaseous emissions, material to be burnt, deposited or treated biologically, etc.

The main problem with these balances is to get hold of the substances being contained in the emissions. In wastewaters most of the pollution is measured by so-called "summarized parameters" (COD, TOC, BOD_5, AOX, electric conductivity, etc.), which give you a rather good estimate of the pollution grade of the wastewater, but no information on the substances themselves and their concentration. To overcome this problem, we took the TOC as basis and calculated a multiplication factor from ca. 40 substances, which we expected in the wastewater streams, and their expected concentrations, to get an estimate for the actual substance concentrations. As far as gaseous emissions are concerned, you do not even have those summarized parameters. In this case, we could only use the substances known to be emitted via wasted air. As far as possible, we did all the calculations with mass streams given as dry matter.

Ecological assessment

Generally, one can distinguish between 2 different approaches to evaluate the environmental impact of emissions:

1. Environmental indicators: Some major environmental problems have been defined and emissions can be evaluated by estimating their contributions to them.
2. Environmental indices: Parameters representing the harmfulness of a product to the environment, obtained by quantitative weighting (Heijungs, 1992).

Environmental indicators

A core set of environmental indicators has been defined in 1993 by an OECD working group (OECD, 1994):

- Climate change & ozone layer depletion
- Eutrophication
- Acidification
- Toxic contamination
- Urban environmental quality
- Biodiversity & landscapes
- Waste
- Natural resources
- General indicators

Although these indicators seem to be a "must" in modern environmental assessment, we decided not to use them in the ecological valuation of our company.

The indicators refer mainly to global ecologic problems and are a very important tool for political decision processes, as they give you an estimation of the state of a certain problem. All of the above mentioned problems need much more attention and much effort is necessary to solve them. But they are not the best tools for the assessment of a rather small production site or of a single product. On one hand, you do not always know how much a given emission actually contributes to a certain environmental problem and, on the other hand, some of the core set indicators are not at all tangled by many production processes, thus leaving a reduced number of indicators to be looked at.

Being established as a means to solve global problems, the environmental indicators cannot be optimally suited for the assessment of a given local situation. For example, as in our case, when you are located on a very small river, the aquatic emissions are more problematic than they were in the vicinity of a big receiving river or even the sea. But the environmental indicators do not take these differences into consideration. By the way, aquatic ecotoxicity seems to be underrepresented in the core set of indicators.

So, from a local point of view, an assessment, which pays regard to the local situation itself, seems to be a better way. Furthermore, the environmental indicators are still heavily discussed and only a small number can be considered to be generally accepted.

Environmental indices

In this chapter all the models have been summarized, which lead to an ecological assessment and differ from the environmental indicators by setting a higher value on local impacts.

Many attempts have been made to evaluate environmental impacts, a lot of different models have been proposed. Each one has its own advantages and shortcomings and at the time being it seems impossible to build a model which is able to overcome all the disadvantages of the already existing models.

Especially the lack of objectivity seems to be the biggest challenge. If you would like to compare different processes or products, the result highly depends on the model used and not so much on the real environmental impacts.

As an eco-balance is incomplete without an assessment of the impacts, you have to decide for a model and the problem is to choose the one, which has less shortcomings than the others.

Though being far from knowing all of the models built so far, I have tried to categorize the models into 5 groups:

1. Science-based models
2. Semi-scientific models
3. Monetary models
4. Energy-based models
5. Quality-goal-based models

Science-based models:

These models are based on scientific knowledge and data. A complex network of transitions between different compartments, combined with degradation rates in these compartments and toxicities against the most important species, should render it possible to estimate the fate of chemicals in the environment and to assess environmental impacts of emissions.

One of these very complex models is the one proposed by some Dutch scientists (Heijungs, 1992, 1992a), one of the best models I have come to know - but only if your data basis is good enough.

In general, the problem with this kind of models is that you hardly ever have enough data to fulfill all the requirements needed for a sufficiently accurate estimation. So you have to rely on assumptions which again make your assessment imprecise. The second disadvantage is that they are rather complicated and hard to apply.

Semi-scientific models:

Models, which use scientific algorithms to deduce relationships between emissions and their environmental behaviour, but - in contrary to the first category - use data which are based on nonscientific decisions, such as limit values, can be called semi-scientific. The problems are again the lack of data, and - in many cases - the algorithms used appear to be chosen at will.

One of the most known models of this type is that of "ecological shortage" (Braunschweig, 1991), existing in some more or less different variations (amongst others: Müller-Wenk 1978, Braunschweig et al. 1984, Ahbe et al. 1990). In general, these concepts are based upon a mass flow-oriented assessment, trying to valuate the ecological harmfulness by the ratio between critical and anthropogenic mass flows. This concept is well established for Switzerland, where the actual loads as well as assessment factors have been defined by a panel of experts (BUWAL, 1990).

Unfortunately, these data are hard to transfer to other countries or regions, so the model would have to be modified, which again causes problems. In addition, the concept of "ecological shortage", resulting in the calculation of so-called "eco-points", is not very easy to understand for "the public". And, as already mentioned, the functions relating maximal and actual loads to one another have to be chosen at will in most cases.

Monetary models:
The costs for prevention or reduction of environmental impacts have a market value, but the environmental quality is not valuable by market mechanisms. Only a small part of the environmental impacts of human activities can be expressed in terms of money.

As a consequence, it is not possible to make an eco-balance solely based on a monetary assessment. Nevertheless, attempts have been made to valuate environmental protection measures. But the result cannot give you any information on environmental impacts, they just relate costs and benefits of the measures to one another.

One example from Austria is the "environmental balance" of a well-known producer of mineral water, which is very engaged in environmental protection (Römerquelle, 1990). The balance lists some activities and compares their costs with those that would devolve if they had not been undertaken. No statement can be given concerning the environmental relevance of the different measures.

Quality-goal based models:
Quality-goal based models are predominantly oriented on limit values. Scientific data, which are often discussed controversially among scientists themselves, are used as a basis for the setting of environmental standards, but are again modified by being subjected to a socio-political decision process. The results are in most cases not the best ones, but they are at least (or have to be) generally accepted.

The Quality-Goal Relationships Concept

After having compared the various models we decided to use the concept of Schaltegger & Sturm (1992) for the valuation of our own mass flow balance.

The concept uses long-term ambient concentrations (limit values) to compare the environmental impacts of different parameters and relates them to the existing CO_2 concentration in the atmosphere.

The conversion of concentrations per liter or cubic metre into concentrations per mol of the environmental compartment allows the comparison of different compartments (air, water, soil) and also the summation of the "environmental impacts added" (EIA; the term is derived from the economical term "value added").

This assessment has some advantages compared to others:
- Results can be compared between various compartments
- The EIAs for different compartments can be summarized to give a single number
- The model can be easily adapted to different regions by just using different limit values
- Once the ambient concentrations are fixed, the assessment is objective
- The procedure is clear and the results are easy to interpret

Of course we are also aware of the shortcomings of this concept:
- Neither biodegradation nor bioaccumulation processes are considered
- The process for establishing the limit values used is not always objective, and sometimes different safety factors are used for air and water
- In some cases it is ambiguous which limit value to use (more than one limits for one parameter)
- Landfills are only considered via their emissions, the volumes being consumed for them have no influence
- The consumption of resources is not taken into consideration
- Energetic outputs are not considered

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LCA-INVENTORIES OF PRINTING PAPERS, FINLAND

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Abstract

This paper describes KCL's activity in the field of life cycle analysis. To illustrate to use of LC inventory tools developed at KCL, a model of fibre flows in the context of Finland/Germany is explained. Also, a recently constructed comprehensive LCI system model is introduced.

Introduction

KCL, the Finnish Pulp and Paper Research Institute, is a company with about 300 employees. It is owned by the main forest industries in the country. The need for LCA inventories became apparent in the early 90's when the market was beginning to insist on the use of recycled fibre in various paper and board grades. A survey on the state of the art and on the means available led to the conclusion that we had to develop tools of our own to cope with the demands of this field.

Practical work commenced towards the end of 1991, involving a small group of 2 - 3 core persons specialized in LCA methodology and programming, as well as a number (appr. 20) of our experts from different disciplines.

LC inventory tools

The first version of the LC-inventory program KCL-ECO (Macintosh) was ready at the beginning of 1993. It was distributed to our owner companies, and besides KCL proper, it has been actively and successfully used by several of them, and by some other research and consulting groups as well.

With the assistance of the said experts, a data bank called KCL-ECODATA has been systematically collected. It is naturally focused on the products and processes of chemical forest industry and its auxiliary services (such as chemicals, energy, transport), and is gradually being expanded and improved. Basically, the data represents yearly average figures of current technology. In this context, the

IMPACT program of J. Pöyry, which was fine tuned in co-operation with KCL, may be mentioned as a specific feature. By means of it, different agglomerate LCI-modules of almost any type of pulp, paper and board mills or their integrates may be calculated.

Currently, a Windows version of the KCL-ECO program is being finalized. It is even more flexible and user-friendly than the earlier Macintosh version.

The two versions of the KCL-ECO programs and the KCL-ECODATA are commercially available.

LCI activities of the Finnish forest industries and KCL

To satisfy the needs of the marketplace, several Finnish companies have applied their LC-inventories to their products and internal processes "from gradle to gate". Such inventories are naturally based on proprietary and specific mill data.

Besides several specific research topics serving common interests of our industry, the role of KCL has been to deal with questions of more global nature. Basically, we have investigated the question which of the two options, intensified recycling or energy recovery from paper, is environmentally preferable when reduction in the landfilling rate is to be achieved. Summaries of such studies have been and will be published.

KCL´s published research

To answer the question posed above, a model of fibre flows was constructed to include all the main product groups, steps and processes. The coarse structure of the paper trade and industry in Germany in 1990 was chosen as a reference, and Finland as an exporter of products to that market. In reality, the flow structure is highly complex involving several loops of recycling, sorting, mixing, downgrading etc.

Newsprint, being less complicated than other products, was the first paper grade investigated (Kärnä, Pajula, Kutinlahti 1994a).

Figure 1 presents very crudely the relative material flows in the reference condition, expressed in kilograms, when **the functional unit was chosen to be 1000 kg of printed newspapers delivered to consumers.**

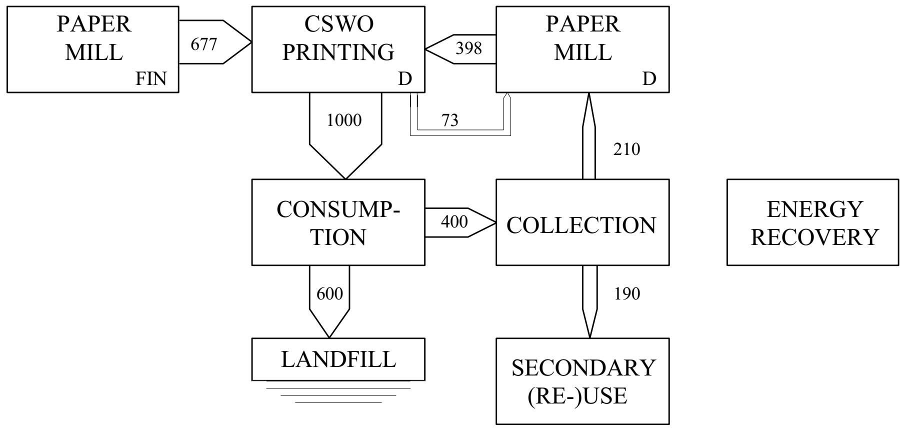

Figure 1. Reference flows in the LCA inventory of newsprint.

In order to demonstrate clearly the effects, two extreme scenarios were then constructed, in which the collection rate of paper was raised from 40 % to 80 %, and the extra amount was either recycled or used for energy recovery.

In the course of the analysis, several assumptions had to be made. Thus, for instance, the average level of technology was assumed to be similar in both areas concerned. The types mechanical and chemical pulps was another choice, which certainly has an effect on the absolute values of energy consumption and emissions, but was not considered to devalidate the relative comparison of scenarios.

The results indicate that in the context studied, energy recovery is to be preferred, as far as environmental aspects like the CO_2-balance (i.e. the difference between CO_2-emissions and CO_2 bound by photosynthesis into the wood used in the system) and several (but not all, however,) other parameters are concerned. This finding stems to largely from the difference in the fuel mixtures used in the production of electrical energy in the two respective areas. Figures 2 and 3 display some examples of the results.

The next step in our LCA work was to look at the magazine grades SC and LWC. Due to the flow structure (with practically no recycling) in the reference condition 1990, it soon became apparent that these grades cannot be analyzed separately as such, but only in conjunction with newsprint. In this instance, we looked into the effects of blending 30 % de-inked pulp into the magazine papers and comparing them with energy recovery from the same amount of extra collected paper. Without going into details, the results follow the same general pattern as for newsprint. The differences are smaller, however, for several reasons. For example, the high pigment content of magazine papers naturally affects their heat value. Furthermore, in this study the change in collection rate was from 40 to 51.4 % only. For more details, see reference (Kärnä, Pajula, Kutinlahti 1994b).

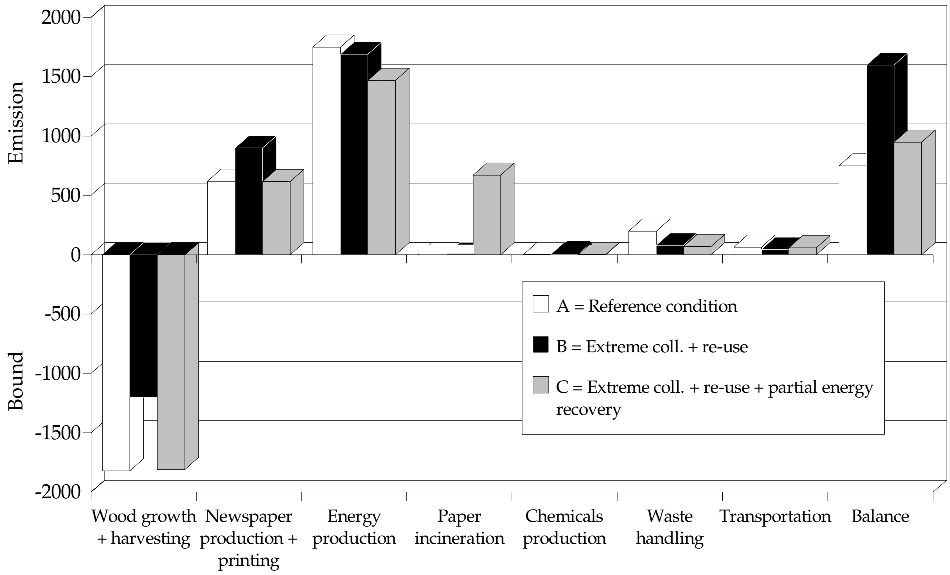

Figure 2. ***Formation of the CO_2-balance in certain agglomerates in three scenarios for newsprint.***

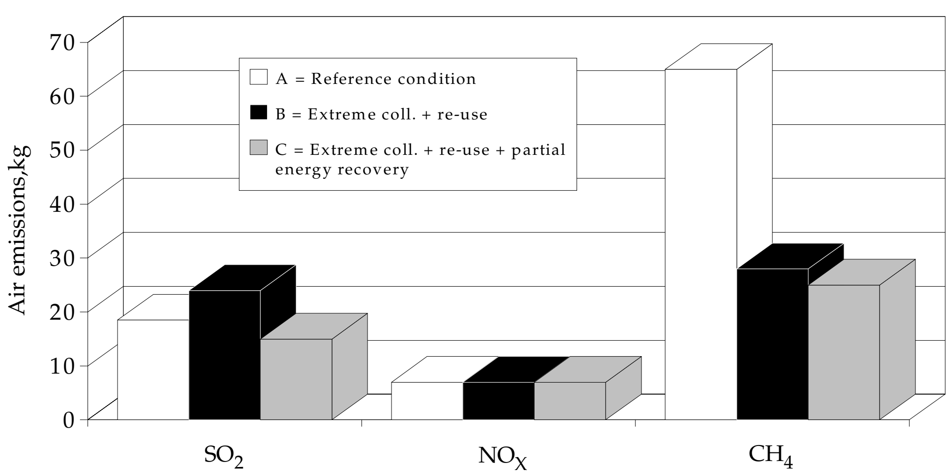

Figure 3. ***Emissions into air in three scenarios for newsprint.***

Current and future research at KCL

Recently, a comprehensive LCI system model, again in the context Finland/Germany, has been constructed. It comprises all main paper and board grades, as roughly outlined in Figure 4. In practice, the working flow-scheme contains about 140 unit modules, 420 flows, 2700 variables, 120 transports and 110 converging or branching flow junctions.

The results of our first studies, again dealing with the same main issue of recycling vs. energy recovery, will be presented in the forthcoming ECOPAPERTECH conference in Helsinki, June, 1995 (Pajula, Kärnä 1995). To compare with the reference situation, we have constructed a scenario where the use of recycled fibre in each grade has been raised to a maximum considered realistic in today's situation. It may be sufficient to state here that the results confirm our earlier conclusions about the environmental preference of energy recovery from paper, whereby the consumption of non-renewable fossil fuels would be reduced.

The extensive system model can in the future be used for investigating several different questions. For instance, products made from virgin fibre may be compared with those containing recycled material, either on the basis of ton vs. ton, or on the basis of equal performance. The effects of changes in the composition of the products or in the performance (level of technology, specific consumption, emissions) of any unit may be conveniently calculated, taking the reflections in the whole system into account. Furthermore, the reference period may need updating. The areal basis of the system may be changed or extended to deal, for example, with the Nordic Countries and Central Europe etc.; the potential applications and modifications are many.

Strengths and weaknesses

Based on our experience, the tools KCL-ECO and KCL-ECODATA are well suited for the tasks described above. The data on paper products and production, pulping and transports can be classified as strong elements in our work.

Due to partial inadequacy of the data (like processes in landfills, some chemicals and to some extent, energy) and adopted system boundaries, the conclusions discussed in the preceding are based on results which can be used for inter-comparisons only. Furthermore, the conclusions are only valid in the context of areas chosen. Thus the results and conclusions could be different if, for instance, Switzerland (with its "cleanly" produced electricity) were chosen instead of Germany, or, on the other hand, the conclusions could be much more strongly supported if the analyses were carried out for Norway/Great Britain, for example. There is room for more work in this field.

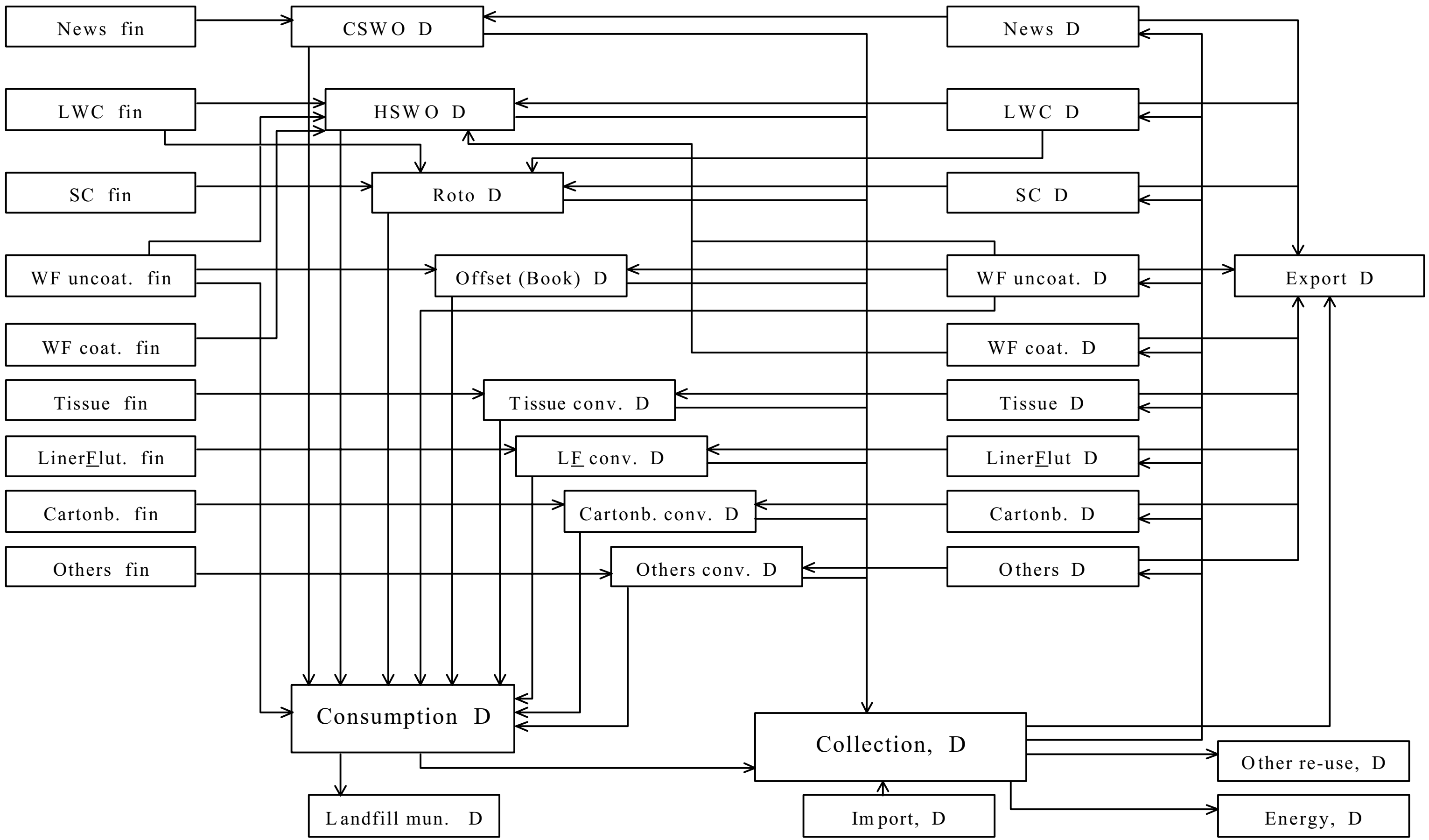

Figure 4. Rough structure of a comprehensive pulp, paper and board system, Finland/Germany 1990.

As regards the LCI-methodology in general, it may be stressed that we have dealt with static system models, based on linear equations. Thus no time series with different growth/depletion rates or accumulations were considered, nor interdependencies between parameters. Furthermore, only the need of resources and amounts of emissions but no aspects related to economy have been estimated. On the basis of the inventory results, some conclusions have been drawn, but no systematic attempt to assess the impacts and effects on the environment has been made.

As can be derived from the preceding, we have not been able to deal with the forest as such in our analyses. We simply and only have considered the amount of wood that was needed in each case. Not the availability of wood nor any changes in the wood reserves (trees as a CO_2-storage), growth rates, etc. were taken as a problem. Under the current situation, the pressures to increase recycling seem not to be increasing, and forestry is in the focus of public interest. Therefore, establishing a link between forestry and the systems of wood-based products in LCA investigations would be most welcome. This is a major challenge, because highly complex and dynamic systems are involved.

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LCAS OF PAPER PRODUCTS - WHAT CAN THEY TELL US ABOUT THE SUSTAINABILTY OF RECYCLING?

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Abstract

This paper considers the extent to which LCA studies can be useful in comparing the sustainability of waste paper recycling and energy recovery options. The concept of sustainability is reviewed and the elements required for its analysis are identified. This is followed by a brief survey of stakeholder concerns about recycling and energy recovery. Some specific LCA studies are then examined in the light of these concerns and conclusions drawn about their contribution to the sustainability debate.

Introduction

Recently, the question has been raised more and more frequently whether the consumption of ever increasing volumes of paper is compatible with sustainable development. Concerns have been raised about fibre production and possible negative impacts on forest resources, about use of chemicals in the production process and the requirements for waste disposal. Environmental groups have called for reduced paper consumption and increased recycling.

IIED has been commissioned by the World Business Council for Sustainable Development to examine the sustainability of the paper cycle. The study which is entitled "The Sustainable Paper Cycle" is in progress and a draft is expected towards the end of the year. The study is looking at sustainability issues worldwide at each stage of the cycle from fibre sourcing through to recycling and disposal and, to the extent possible, is examining linkages between different stages of the cycle. One policy debate which requires analysis of the whole cycle is the choice between recycling and incineration. Which of these options is more sustainable? One of the methodological questions to address in the initial stages of the study was the extent to which LCA analysis could contribute to this issue.

The aim of this paper is to review some of the LCAs which compare paper recycling and energy recovery scenarios and consider what they can tell us about the relative sustainability of these options. The concept of sustainability is first reviewed and the elements required for its analysis are identified. This is followed by a brief survey of stakeholder concerns about recycling and energy recovery. Some specific LCA studies are then examined and conclusions drawn about their contribution to the sustainability debate.

The concept of sustainabilty

Numerous definitions of sustainable development and sustainability have been offered. An early definition was given in the World Conservation Strategy (IUCN/ WWF/UNEP 1980) which emphasises that "for development to be sustainable it must take account of social and ecological factors as well as economic ones". One of the most well known definitions of sustainable development is that of the Brundtland Report (World Commission on Environment and Development, 1987) which defines it as progress that "meets the needs of the present without compromising the ability of future generations to meet their own needs". This apparently simple definition raises numerous contentious issues of interpretation. Subsequently, the United Nations Conference on Environment and Development (UNCED, the Earth Summit of 1992) in its action plan, Agenda 21, emphasised the three systems basic to development: the *ecological* system, the *economic* system and the *social* system and the need to apply an integrated approach to them.

Thus a key element of the concept of sustainability is the requirement to balance social, environmental and economic factors. This implies the need for trade-offs between potentially conflicting goals, such as between narrow economic growth and environmental conservation. These trade-offs have to be faced at a number of levels: global, national and local, and solutions will vary depending on the context. This raises the question of how these decisions on trade-offs should be made. Agenda 21 calls for the widest possible participation in decision-making. Hence consensus building and conflict resolution amongst stakeholder groups are important. For this reason, it is necessary to examine the perspectives of different stakeholder groups and understand their concerns.

Stakeholder concerns about recycling and incineration

Analysis of literature produced by environmental non-governmental organisations (NGOs) indicates the following concerns:

- Pressure on natural forests - "Save a Tree": NGOs argue that recycling by diverting demand away from wood pulp can reduce pressure on natural forests. This reflects a view that current forest management practices are unsustainable. "The pressure on the forests would be greatly reduced by using timber as efficiently as existing technologies now permit, and by recycling more paper" (Archarya - Worldwatch Institute 1995)

- Water and energy use: Pulp and paper production is energy intensive and water intensive in comparison to other industries. Recycling is claimed to reduce the consumption of both considerably (Greenpeace 1990).

- Recycling (Deinking and repulping) Environmental groups acknowledge that deinking of waste paper can involve some harmful impacts but claim that this can be reduced through the use of less toxic inks and additives in production and converting.

- Incineration impacts: One of the principal concerns is the emissions of heavy metals and dioxins from incineration because of their carcinogenic effects and effects on immune systems. There are also concerns about the local nuisance effect of both incinerators and landfill, for example, the noise and emissions from lorries transporting waste. Community opposition to disposal facilities can have an important effect on location and the ease of finding appropriate sites. It is also argued that once an incinerator has been put into operation the need to keep it supplied can close off options for recycling.

LCA studies of waste paper recycling vs incineration

Against this background of popular concerns about recycling, it is interesting to examine the conclusions of the LCAs that address this difficult area. A number of studies have been carried out in Europe and North America. Some of these analyse paper products in general, others look at a particular type of paper product, newsprint mainly. All point tentatively to the same conclusion that energy recovery may be preferable to recycling on environmental grounds. However, in most cases they acknowledge that certain adverse environmental impacts will increase under an energy recovery scenario.

Details of the studies are given in Table 1. Some key features of the studies are as follows:

- Greenhouse gases: All the studies analyse CO_2 emissions. Most include CO_2 uptake from growing trees as well as CO_2 emissions from energy consumption. The exceptions are the studies by Johnson and Porteous. All except Gilbreath (undated) include methane emissions from landfill.

- Air pollution: Most include SO_2, NO_x, and particulates and some consider a more extended list of pollutants.
- Water pollution: Not all of the studies include water pollution. Those that do focus on COD and AOX. Some also include BOD.
- Solid waste: Some of the studies estimate volumes of industrial waste i.e., sludge from recycling and incinerator ash and municipal waste i.e., waste paper.

Systems boundaries

With regards systems boundaries a common feature of all of these studies is that they exclude forestry from the system. At other stages of the cycle there are some differences in system boundaries but these do not seem to affect the overall conclusion. Most of the studies address the changes in consumption of inputs under different scenarios, not only wood but also chemicals and additives. However, in most cases, the boundary is drawn at input consumption; the environmental impacts of extraction or production of fuel, chemicals and additives are not included. The exceptions are the studies by Kärnä *et al* and Virtanen and Nilsson, which include the environmental impacts of the production of chemicals and additives. The latter study also includes the impacts of coal mining, oil refining and other aspects of primary energy production. Kärnä *et al* exclude energy extraction but do include in the case of nuclear power, the effects of mining and concentrating uranium ore.

The match with stakeholder concerns

The conclusions of the LCA studies appear to conflict with the concern of some environmental groups that there should be more recycling. It is therefore important to examine the extent to which they address the arguments made in favour of recycling.

Fibre production

While all the studies except that of Johnson (1993), and Porteous address the CO_2 implications of forestry and harvesting, most do not address the issue of wood consumption and the environmental impacts of forestry, for example, the use of fertilisers and pesticides in plantations. The assumption, in some cases explicit, in others only implicit, is that the fibre comes from a sustainably managed source. Wood consumption although acknowledged to be lower under a recycling scenario is therefore not considered to be an issue.

Thus one of the main arguments for recycling, that it may reduce pressure on natural forests, is not addressed in most of the LCA studies. The exception is the study by Virtanen and Nilsson which argues quite the opposite. The study estimates the thinning volume required for long-term sustainability of European timber resources and concludes that it exceeds fibre requirements under the different recycling and energy recovery scenarios examined (Virtanen and Nilsson 1993). The conclusion drawn is that recycling by reducing the demand for thinnings may actually be detrimental to the health of European forests. This reflects a view that thinning is an essential element of forest sustainability. Some environmental groups do not share this view and have argued that the practice of thinning and the even-aged stand management it is associated with may be detrimental to other forest values (Kuvaja 1994).

If fibre is believed to come from unsustainably managed sources then any option that reduces virgin fibre consumption can be considered in a static sense to bring environmental benefits. This leads to difficult questions of definition. What criteria do we use to judge whether a fibre source is sustainable or unsustainable? Some groups consider clearcutting to be unsustainable while others emphasise its beneficial effect on regeneration. While some stakeholders emphasise the renewable nature of the forest resource, other groups argue that the need to phase out unsustainable practices effectively places a finite limit on forest resources. A recent report by Friends of the Earth UK estimates the ecological carrying capacity for the world's forests for the year 2010 based on assumptions such as an end to clearcutting, conservation of most remaining primary forest and a very restricted use of plantations (FOE 1995). The implication is that there is a finite limit to fibre production for paper. Under these assumptions reduction of virgin fibre consumption through recycling would be considered beneficial.

Even if agreement could be reached on a definition of sustainable fibre sourcing, it is doubtful though that the LCAs could address this issue as it involves more dynamic questions of how markets respond to changes in the supply of recycled fibre. Recycling may lead to reduction in wood consumption but does this necessarily have any beneficial effect on forest management? It could be argued that areas introducing more sustainable practices will see an increase in production costs and will therefore be most vulnerable to competition from recycled fibre. Much depends on other drivers such as the regulatory framework and consumer pressure. Recycling may facilitate the implementation of measures to promote sustainable forest management but on its own there is no guarantee that it will lead to sustainable fibre sourcing. This implies that an LCA will be insufficient to address this issue. What is needed is an economic analysis of the drivers of sustainable forest management, the cost structures of different fibre sources and how the effect of recycling on fibre supply patterns.

<u>Energy consumption</u>

The major focus of these LCA studies is on emissions associated with energy use. They therefore address a major concern of the NGOs. However, emphasis is given to the type of energy consumed rather than the volume and a key distinction is made by all the studies between renewable and non-renewable energy sources. While it is acknowledged that recycling will involve less energy consumption its effect is to shift energy use to fossil fuels in the generation of electricity. Whereas with chemical pulping the by-products of the pulping process are normally burned to provide most of the energy requirements, the recycling process is reliant on external energy inputs, i.e., electricity.

The question of energy type is also relevant to the combustion of wastepaper as this will enable generation of electricity. This will imply displacement of electricity from other sources. The extent to which this is a benefit depends on the fuel mix for electricity generation in the country concerned. Options which involve production in Scandinavia where hydroelectricity and nuclear power are important, appear more favourable in the studies than those based on production in countries relying more heavily on fossil fuels. This raises issues about the impacts of these renewable energy sources as these are not included in the life cycle inventories.

Water consumption

The LCA studies give very little attention to water consumption. Only one of the studies reviewed, that by Johnson, has estimates of water consumption in the inventory and concludes that it would be lower under an energy recovery scenario than under a high recycling scenario. This is surprising given the emphasis on recycling as a potential water saving option.

Incineration impacts

Most of the emphasis is on emissions associated with energy use, mainly CO_2 and conventional pollutants such as SO_2, NO_x and particulates. Little attention is given to other emissions from incineration such as heavy metals and halides, including dioxins. In some cases some of these are included in the inventories but little mention is made of them in the discussion of the results. It may be that waste paper is not a major contributor to such emissions in the incineration process or it may be that not enough is known about the effects of the level of emissions involved. Either way there would be advantages in giving more attention to these emissions given the popular concern over them.

Technology issues

The LCA studies involve a series of assumptions at each stage of the life cycle on the different production or control technologies employed. These reflect differences in location and industrial structure. The effect of possible improvement options is generally considered outside the scope of these studies. For example, there is little attempt to examine the extent to which de-inking be made more environmentally friendly as the environmental groups advocate, or to assess the options for using renewable energy sources for recycling. Virtanen and Nilsson without going into quantification argue that if some of the chemicals, and heavy metals used in the pulp, paper and printing processes were replaced with other materials, waste paper could be classified as a clean fuel. However, such changes would also affect the impacts of recycling. This points to the need for more systematic analysis of the impacts of technology and input change within the LCAs.

The need to integrate social and economic aspects

LCAs have conventionally focused on environmental impacts. As discussed earlier, for analysing the sustainability of recycling it is important to be aware of the economic and social trade-offs involved as well as the environmental effects.

The choice of disposal option for waste paper has economic implications. Incineration is often more expensive than landfill. Recycling may be more expensive than incineration depending on the source of waste paper. When waste paper comes from commercial sources it can be a relatively cheap source of raw materials. The economic situation can be different when attempts are made to raise the level of recycling to include mixed waste paper from household sources. The costs of collection and sorting of household waste paper can often outweigh the financial benefits from sale of materials and reductions in waste disposal cost.

In the UK, kerbside recycling has been estimated to cost US$ 88-280 per tonne of mixed recyclables net of revenues. The costs of incineration are estimated at US$24-48 per tonne rising to £48-56 per tonne by 2000, somewhat less than the costs of kerbside collection (DOE 1993a). In the US where there is more experience with kerbside recycling, costs are somewhat lower at US$65-93 per ton of newspaper and US$90-150 per ton of mixed recyclables (NSWMA 1994). However, this still appears to exceed the cost of incineration which is estimated at US$45-65 (SWANA 1995) though it can be considerably higher in some locations.

For low to medium levels of recycling based largely on commercial sources there may be a conflict between the economic advantages of this option and the possible environmental disadvantages as indicated by the LCA studies. For high levels of recycling, there may be economic disadvantages as well, thus reinforcing the conclusions of the LCAs. In both cases however, it is necessary to consider the impacts that have been left out of the LCAs before drawing any firm conclusions.

The environmental impact at various stages of the lifecycle will also depend on the extent of emission control or on changes to technologies and inputs. Again there are economic trade-offs involved. For example, emission standards for incineration in the Netherlands and Germany are considerably stricter than new standards proposed for the UK and as a result the gate fees in these countries are more than double those projected for the UK under the new standards (Scutter and Dyke 1994).

Social issues also have to be considered, in particular, the possibility of community opposition to incineration facilities. Most of the LCAs studies avoid this issue as they assume that the energy recovered will be used for heat production in pulp and paper mills. Only two (Porteous and Johnson) consider the option of paper disposal through municipal mass burn incineration. Yet the latter appears to be a more relevant option for waste disposal authorities faced with large volumes of mixed household waste. It is likely that industrial use of waste paper for energy recovery could have much less serious social and NIMBY implications than mixed waste incineration. It therefore seems an attractive option. It would, however, require the separation of waste paper from other types of waste leading to economic issues of the cost of collection and sorting. It would also have to be compared with the price of other fuels.

Conclusions

The LCA studies reviewed have interesting conclusions with respect to the use of fossil fuels and associated environmental impacts in recycling and energy recovery scenarios. Recycling appears less favourable than energy recovery mainly because it involves more use of fossil fuels. The critical variables in these studies for determining which option is more environmentally friendly therefore appear to be:

- the energy source for virgin fibre pulping
- the energy source for repulping/deinking
- the energy source replaced by electricity generated from incineration

With regards other environmental impacts some of the key concerns of environmental NGOs are not addressed. Only one study addresses the issue of forest sustainability. In all the others, changes in wood consumption are not considered to be an issue. It is unlikely though that LCAs can deal adequately with the debate on the link between recycling and sustainable forest management. A broader analysis of the effects of recycling on fibre supply patterns is required. Another key issue not addressed is the question of emissions of less conventional pollutants from incineration, one of the key concerns of environmental groups.

It is also necessary to examine social and economic issues associated with recycling and energy recovery. Both these options can be costly in relation to other disposal practices such as landfill. High levels of recycling may involve considerable expenditure on sorting and collection. These economic costs need to compared with the environmental impacts of the scenarios. The environmental impacts at each stage of the cycle are also dependent on the assumptions made about production and environmental control technology. Some exploration of the trade-offs involved in adopting technologies which in result in lower environmental impact is needed.

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Table 1. Life cycle studies of paper recycling and energy recovery.

Study	Location	Scope	Scenarios Compared	Extent of Cycle Analysed
IIASA (Virtanen & Nilsson 1993)	Scandina-via Central Europe	7 paper categories 4 pulp grades 1 reuse pulp	1. Maximum recycling 2. Selective recyling 3. Maximum energy recovery	Wood harvesting to waste disposal including transport and energy extraction
KCL (K rna *et al.* Undated)	Germany	Newprint	1. Current situation - 40% collection 60% landfill 2. Collection 80%, 20% landfill 3. Collection 80% - 50% to energy recovery 50% to recycling	Wood harvesting to waste disposal. Including: Production of chemicals and additives Energy combustion but not energy extraction except for nuclear (mining of uranium) Transport of inputs and outputs
Ebeling et al 1992	Europe	European paper production	1. Average European recovery of waste paper of 1/3 2. Average European recovery of waste paper of 3/4 3. Recovery of 3/4 of waste paper for energy recovery	Forestry, pulp and paper making, transport, recycling and waste management
Johnson (1993)	UK	Newsprint	1. 100% recycling 2. 100% energy recovery and production in UK 3. 100% energy recovery and production in Scandinavia	Pulp and paper manufacture, recycling, transport, mass burn incineration
Jaakko Poyry (Jerkeman 1993)	Sweden	Newsprint and liner	1. 100% increase in usage of recycled fibre 2.In addition 0.5Mt used for heat production in the mills	Wood harvesting, pulp and paper manufacture, transport, recycling and dedicated energy recovery
Gilbreath (Undated)	US	Container - board, kraft paper	100% virgin fibre or 100% recycled fibre with or without installation of waste paper boiler to replace 3 fossil fuel boilers	Wood harvesting, pulp and paper manufacture, recycling and dedicated energy recovery
Porteous (1992)	UK	Newsprint	1. 100% recycling 2. 100% landfill 3. 100% energy recovery	Collection of waste paper to deinking, energy recovery or landfill including transport
IFEU (Flood 1994)	UK/ Sweden	Newsprint	1 tonne of newsprint from 100% UK waste paper processed in: 1a. UK 1b. Sweden Paper waste burned in UK with newsprint produced : 2a. in UK with UK timber 2b. in Sweden with Swedish timber	Pulp and paper manufacture, recycling, transport, energy recovery

Impact categories	Key Assumptions	Conclusions
Energy demand, raw material demand CH_4, NO_x, SO_2 CO CO_2 emissions and uptake, BOD, COD, AOX Solid Waste	Production structure constant Thinnings volume required for long-term sustainability exceeds fibre requirements in Europe	Preliminary only Maximum recycling increases consumption of fossil fuels and increases emissions of SO_2 No_x and net CO_2. Balanced mixture of recycling and energy recovery seems to be a suitable solution.
Wood consumption CO_2 emissions and uptake, CH_4, SO_2, NO_xVOC CO COD, AOX Solid waste - industrial/municipal	Conclusions relate to reduced CO_2 CH_4 SO_2 AOX. But NO_xVOC and wood use all increase. Non air Environmental impacts of nuclear and hydro not considered	Preferable to 1. Recover heat from waste paper 2. Import waste paper to Finland and deink there
Global warming, acid rain, energy demand BOD COD AOX	Fibre production is beneficial for forests	Scenario 2 better than 1 except for 2 criteria global warming and forest status. Scenario 3 (Energy recovery) better than 2
Air: CO, CO_2 emissions, NO_x SO_2VOC (including CH_4) dust halides Water: TDS, TSS, COD, BOD Solid waste: weight and volume, heavy metals, oils and grease	Forest management outside system boundaries Scandinavian mills generate energy from wood wastes	Incineration in UK of newspaper produced Scandinavia has advantages over recycling If newsprint produced in UK comparison i less clearcut
Wood consumption, CO_2 emissions and uptake, energy consumption, SO_2	Forest management not addressed or assumed sustainable	Energy recovery scenario reduces oil consumption SO_2 and CO_2 emissions but tranport emissions increase
Biomass energy use, fossil fuel energy use, CO_2 emissions and uptake air pollution solid waste	CO_2 credit applies for sustained management practice defined on yield basis Transport not included	Recovery of fibre as a fuel produces a significant positive environmental impact
Primary energy, CO_2 emissions, CH_4		Energy recovery has lower greenhouse gas emissions than recycling
Energy and CO_2 emissions	Planting, tending and harvesting of timber excluded Chemical pulping in Sweden assumed	In terms of energy CO_2 burning of paper waste (option 2b) the best option

LCA ON THE DISTRIBUTION OF FILLER GOODS IN PAPER SACKS: A EUROKRAFT-EUROSAC PROJECT

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Abstract

Eurokraft is the organization of the European sack paper makers, and Eurosac the corresponding organization for the paper sack makers. They have formed an LCA working party chaired by G. Swan. The aim is to study and inform of the environmental life-cycle conditions of particular mass goods distribution, especially those of paper sacks. This paper gives a preview of the first report, which is soon being published. Although sacks made of kraft paper was the main goal of the study, a polyethylene alternative was also included in the study, the general lay-lout of which is described below.

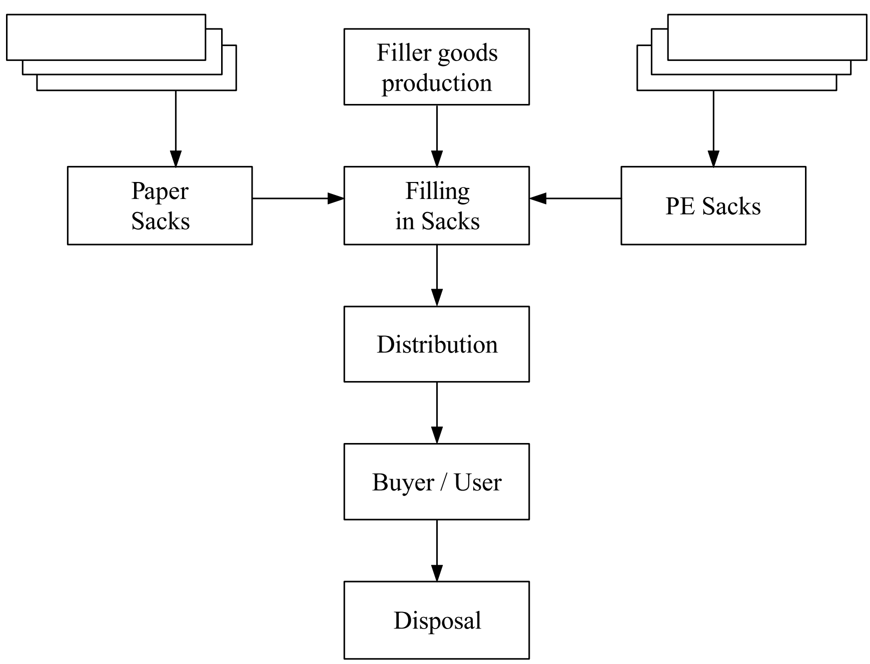


Figure 1. ***The general structure of the study.***

Functional unit: The distribution of one tonne of filler goods in sacks. Besides the loads coming from the production of sacks, the filling and the distribution of the filled sacks to the end user is included, but not the loads of the filler material.

Organisations involved:

- Eurokraft: Sack paper makers in Europe
- Eurosac: Paper sack makers in Europe
- LCA working party with members from Eurokraft and Eurosac
- Ecobilan, France: made the inventory
- Chalmers Industriteknik, CIT: made the assessment and wrote the report
- Center of Environmental Science Leyden, CML: made the critical review

Goal

- Study distribution of particulate animal feed in (small) sacks
- 25 kg sack, 2 unbleached plies
- 25 kg sack, unbleached + bleached ply
- 40 kg sack, 2 unbleached plies
- 40 kg sack, unbleached + bleached ply
- 25 kg sack of PE (polyethylene)
- 40 kg sack of PE

Scope - boundaries

- Cradle for main data = nature
- Grave: incineration + energy recovery, or landfill, but borderline before the landfill
- Some auxiliary chemicals data not followed back to cradle or to grave
- Material recycling not included

Scope - data

- Forest inventory data from Sweden
- Pulp and paper data from E-kraft mills
- Paper sack data from E-sack factories
- Filling data from Haver & Boecker
- End-of-life processes from Ecobilan
- PE data from APME/PWMI study

The PE data from PWMI (Plastic Waste Management Institute) are weighted averages over a pretty high portion of the western European production of PE. Thus our aim was to get corresponding figures from the Western European production of sack paper, which we also managed to get.

Interpretation of results:

- Based on the inventory results
- Based on classification and characterization results
- Based on valuation results

The inventory results are everywhere accepted as a good base for the interpretation of the results. Classification followed by characterization is also accepted as a "scientific" approach, although different approaches are still occurring.

The valuation has been made with two methods; The EPS method (Environmental Priority Strategies in product design) and WET method (Weighted Environmental Theme). Both valuate resources as well as emissions, but with different weights.

Inventory results

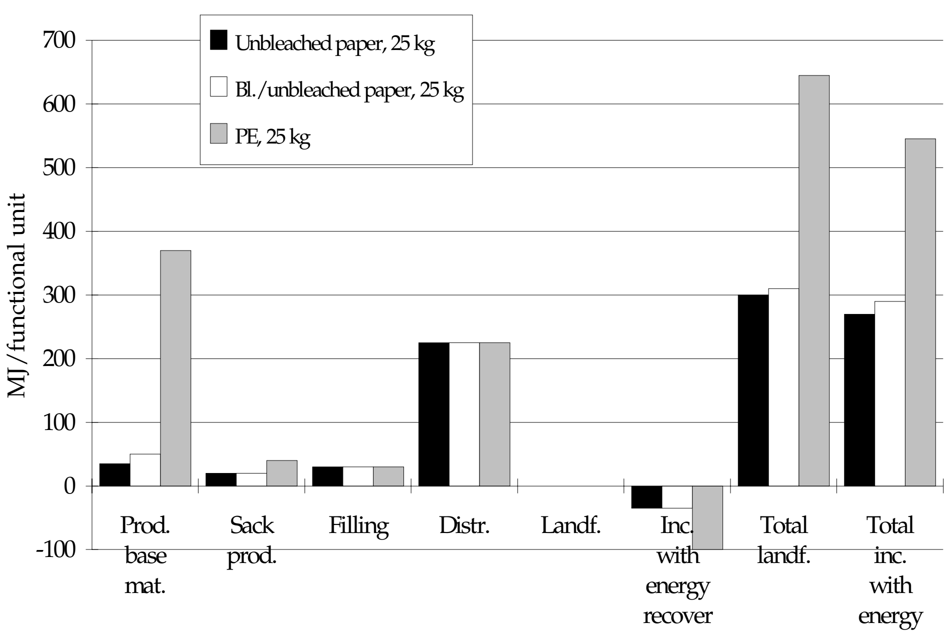


Figure 2. Use of non-renewable energy. Comparison different sack types for 25 kg filler goods.

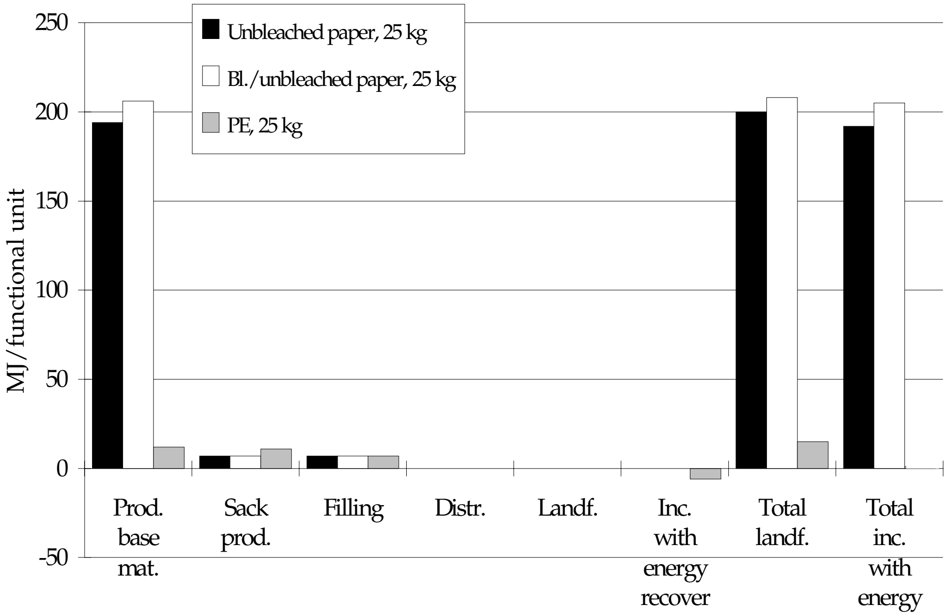


Figure 3. ***Use of renewable energy. Comparison different sack types for 25 kg filler goods.***

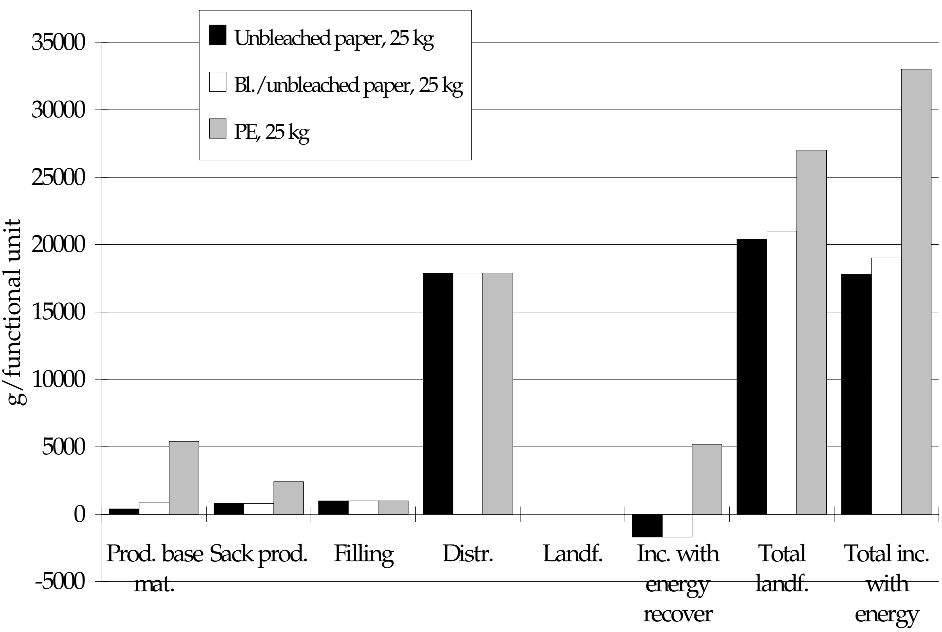


Figure 4. ***Emissions of CO_2. Comparison different sack types for 25 kg filler goods.***

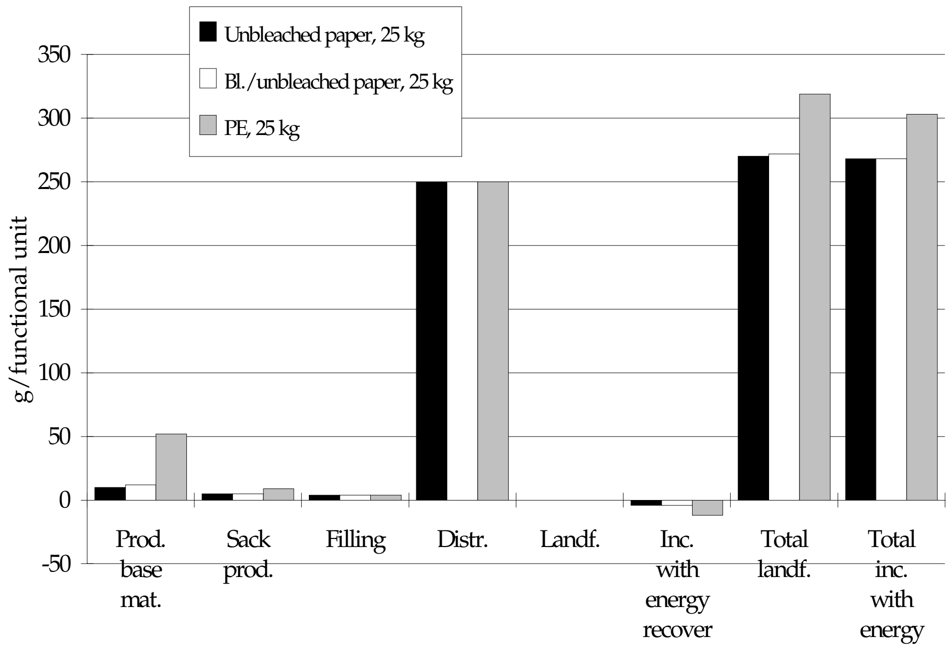


Figure 5. Emissions of NO_x. Comparison different sack types for 25 kg filler goods.

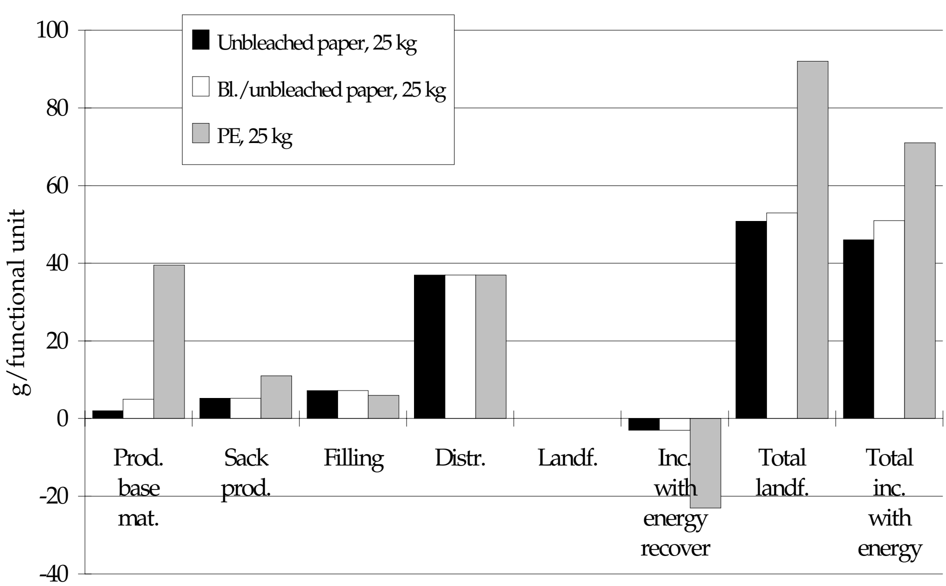


Figure 6. Emissions of SO_x Comparison different sack types for 25 kg filler goods.

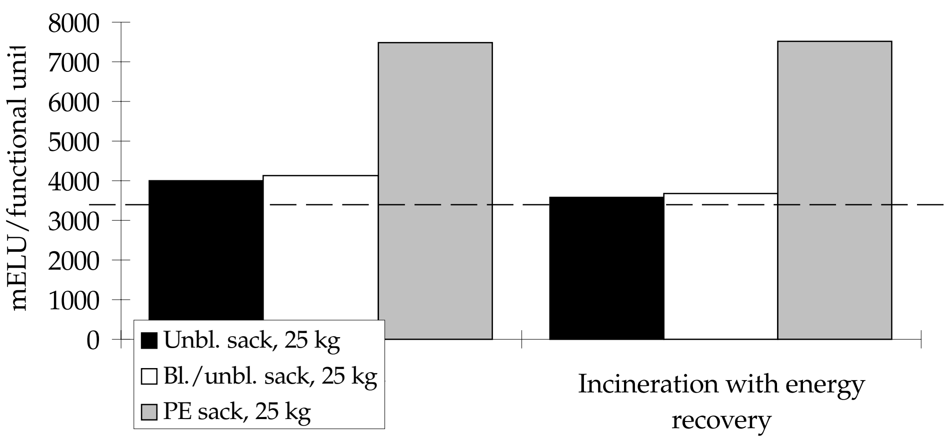
The valuation presents a single figure for each alternative. In this case three of the cases are illustrated with (milli) Environmental Load Units (EPS):

An unbleached sack for 25 kg filler material
A sack with a bleached outer ply for 25 kg filler material
A PE sack for 25 kg filler material

Those three alternatives are presented with two disposal alternatives; Landfilling and incineration with energy recovery. The broken line indicates the contribution from the distribution step. Apparently the distribution of one tonne of filler goods (for 300 km) takes much more environmental load than the life-cycle of the packaging - at least for the paper alternatives.

Already after the inventory step it could be shown that the PE sack needed roughly twice as much non-renewable energy resources as the paper sacks. This is not counterbalanced by the fact that paper sacks need much more renewable energy, because by the valuation, much more weight is laid on the use of nonrenewable resources.

The emissions released to the air, here represented by (fossil) CO_2, NO_x and SO_x gases, are also very much linked to the use of fossil resources. The releases to water (not shown here) are higher for the paper sack alternatives, but again, it does not counterbalance the emissions to the air, shown above.



The result of the study is that it is better to use 25 sacks , each for 40 kg filler goods than to use 40 sacks for 25 kg filler goods (not shown here). It is also better to use two plies of unbleached paper than having an outer ply of bleached paper, although the difference is small.

Using PE sacks result in a higher environmental load for the purpose studied. Yet the PE sacks were made in the form-fill-seal style in order to choose a competitive alternative (from the cost point of view, the PE sacks are cheaper). Landfilling gives a (slightly) higher load than energy recovery. Recycling will probably be studied later.

EXPERIENCES WITH LCA IN THE PULP, PAPER AND PACKAGING INDUSTRY IN NORWAY

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Abstract

Arguments in favour of applying Life Cycle Assessment in the pulp and paper industry are as follows: LCA is a useful tool in the development of new products, it may be used in the process of selecting the most environmentally friendly product and it may be used to identify the points in the production process which gives the highest environmental impacts.

The Norwegian Environmental Authorities have been an active participant in the work of developing the method of LCA and have stated that, in some cases, LCA will be required in the licensing process of discharge permits.

This paper gives an overview of the environmental impacts from different scenarios of recycling and incineration of used barrier cartons, and discusses briefly the specific problems of this LCA analysis. The study can be seen as an example on how LCA may have a role to play as a decision making tool where there are many environmental parameters to overlook and several solutions to choose between.

Background

Oestfold Research Foundation (Stiftelsen Østfoldforskning) is a regional research institute, and is regarded as the leading institution in research in Life Cycle Assessment (LCA) in Norway. Oestfold Research Foundation has been working with LCA on paints, fuels, lubricating oil, concrete products, electric equipment, furniture, packaging and plastic products, and has been an active participant in the development of the Nordic Handbook on LCA[1]. Oestfold Research Foundation is acting as a project leader for the Nordic Project in Environmentally Sound Product Development.

[1] Nordic Council of Ministers; LCA Nordic 1995.

Oestfold Research Foundation does have experience from the pulp and paper industry from projects in Cleaner Production and Waste Minimisation, and from Life Cycle Assessments of packaging materials.

In this presentation the focus will be on the following points:

- the work on LCA by the Norwegian State Pollution Control Authority
- the response by the pulp and paper industry on LCA
- examples of LCA projects within the branches of forestry and pulp and paper
- example on LCA used to compare the total environmental impacts from waste treatment and recycling of an barrier carton (or how LCA may be used in a decision process).

Several people, most of them from the pulp and paper industry and a few persons from the forestry industry, have shared their views on LCA in general and given information on LCA-work in their companies or associations. Their views are not the official view of the branch as a whole, rather some personal opinions from people representing the pulp and paper industry.

The approach and strategy from the Norwegian environmental authorities on the use Life Cycle Assessment.

One very important principle in the Norwegian environmental policy for the last decade has been the «cradle to grave»-principle. The development of the methodology for Life Cycle Assessment has helped to effectuate this principle from theoretical rhetoric into a more practical approach. The Norwegian State Pollution Control Authority has been an active participant in the work with development of the LCA-method through the Nordic LCA-project, and is also following very closely the Nordic work on LCA in Product Development.

The State Pollution Control Agency has stated that in the process of issuing new discharge permits, LCA will in some cases be required. Already in 1990 the State Pollution Control Agency required an LCA-analysis before licensing a permit for a new PVC-plant in Norway.

The State Pollution Control Agency has also applied LCA in their evaluation of total product systems, such as reuse or recycling of packaging materials.

The response from the pulp and paper industry on Life Cycle Assessment

There are mixed responses from the pulp and paper industry on the use of Life Cycle Assessment. Some companies has taken the challenge and initiated their own work to collect data and carry out life cycle assessment of their activities and products. Others have a more reluctant attitude towards the method, and have the opinion that the method is not fully developed to be used as a tool for the industry. Nevertheless, there is a general impression that the industry as a whole is well informed about the progress and activities with development of the LCA-method.

Some pulp and paper companies has established their own expertise in the field of LCA on the corporate level, and carry out LCAs of their own product system and the systems of their subcontractors. The following reasons has been given for this strategy:

- Life Cycle Assessment is seen as a useful tool in the development of new products.
- Life Cycle Assessment may be used in the process to select the most environmentally friendly product. It is emphasised that it may be difficult to get a just result from such comparisons because different system boundaries in the assessment will lead to different answers.
- Life Cycle Assessment may be used as a tool to identify the points in the production process which gives the highest environmental impacts and where the potential of improvement is the highest.
- Having carried out Life Cycle Assessments of own products give much better cards on hand in the communication with local and national environmental authorities.

A common experiences with LCA-projects is that the gathering of energy data and emission data from the production process and the raw materials, is a much larger task than assumed. Even if there is a good knowledge of the total emissions and the energy demand of the factory, the processes are often integrated, and there are problems allocating the different emissions to the products. In addition to the internal problems of finding the correct data from the manufacture processes, there are problems to procure data from the processing of raw materials (forest products and chemicals). At least two pulp and paper plants are using students in their work to establish the data base for a Life Cycle Assessment. In that way they are supervising a student project, and are initiating their own work in LCA.

Examples of projects involving the Norwegian forestry and pulp and paper industries which includes an LCA approach

<u>The Nordic Project on Environmental Sound Product Development (NEP)</u> was started in 1993 with the goal to introduce and develop methods for environmentally sound product development. There are altogether 21 companies from the Nordic countries involved in the project. Six out of a total of 21 participating companies from the Nordic countries are representing the pulp/paper and packaging industries: Peterson, Elopak, Tetra Pak, Stora, Korsnäs and Iggesund. The project

has been divided into three subprojects:
1. Development of LCA data tools (data base)
2. Development of methods for sustainable product development
3. Development of a handbook and education programmes.

The second subproject on development of methods for sustainable product development are focusing on key parameters such as customers requirements, life cycle economy and environmental performance to establish a set of evaluation criteria for product related decision making. The method is developed based on a number of case studies. The method aims at integrating existing methods used in product development such as Quality Function Deployment (QFD), Life Cycle Cost Analysis (LCC) and Life Cycle Assessment (LCA).

There are initiated at least two larger branch projects within the forestry and pulp and paper industry in Norway which includes Life Cycle Assessment.

Environmental impacts by the use of paper is the title of a project conducted by The Foundation for Scientific and Industrial Research (SINTEF), the Research Institute for Pulp and Paper Industry (PFI) and the Environmental Committee of the Pulp and Paper Industry (Treforedlingens Miljøutvalg). They assess the environmental impacts from the production and use of paper. The goals of the project are:
- to draw up a method for environmental assessment of paper products
- to establish environmental specifications on paper products
- to carry out an environmental analysis of some representative paper products.

The approach of Life Cycle Assessment will be included in the environmental analysis of the products.

A project which is planned to be started up in June 1995 is a branch project regarding sustainable development in the Norwegian forest industry. The project is run by group of the largest interestholders in Norwegian forestry and forest industry. Some of the defined activities in the project are to establish criteria and documentation for a sustainable forestry, and to set conditions and establish a strategy for a sustainable forestry industry.

Example of a possible use of LCA in decision processes

Over the recent years, the Norwegian Ministry of the Environment has made numerous decisions on how to reach environmental goals set by the Norwegian government or by international bodies. One common practice to approach these problems has been to apply cost/benefit analysis and to assess the social economic aspects of the possible solutions.

The Ministry of Environment has, in co-operation with branch organisations and representatives for the consumer organisations, decided to establish a recycling of the fibres from used milk cartons in Norway. The fibres from the used cartons will be collected and recycled and used in other products, and the barriers of the carton (plastics) will be incinerated for energy purposes. The aim is to collect and recycle 60% of the total amount of fibre used for milk cartons in Norway, estimated to a total of 12.000 tons in 1996. 60% of the milk cartons represents the amount of used milk cartons in the centrally located areas around the Oslofjord, and some other larger cities in Norway.

Oestfold Research Foundation has recently made an assessment of the environmental impacts of different types of packaging and this study we also included a barrier carton for detergents. In the study, we looked upon the environmental impacts of such a carton from manufacture until it was put on the landfill or incinerated after use. The general results from the packaging study showed that for most packaging systems the main environmental impacts were generated at the production of the material and at the treatment of the used packaging (waste treatment). Therefore, a higher degree of recycling or reuse of a material would be favourable. Would this also be the result of the LCA of a barrier carton - a packaging with a high energy content, and where the main part is made of a renewable material?

The detergent carton differs from a milk carton when it comes to type of barrier, but may be recycled like a milk carton. The type of life span of the detergent carton is also very similar to the life span of a typical milk carton, both are sold by any grocery store and both are (up till now) normally thrown in the garbage bin after use. (The manufacture of the different barriers of the carton may differ significantly).

The environmental impacts from a typical life span of a detergent carton in Norway today is defined as following:

0. 100% of the used cartons goes to the waste management system, where 35% is incinerated (60% of the energy is recovered, and is replacing hydroelectric power).

This system was then compared to the following 4 scenarios:

1. 60% recycling of the fibres from the carton, and regular waste treatment of the remaining 40% (35% incineration and 65% land fill). The produced energy from the incinerated part is replacing hydroelectric power.
2. 60% recycling of the fibres from the carton, and regular waste treatment of the remaining 40% (35% incineration and 65% land fill). The produced energy from the incinerated part is replacing fossil fuel.
3. Incineration of 95% and deposition of 5% of the cartons on land fills. The produced energy from the incinerated part is replacing hydroelectric power.
4. Incineration of 95% and deposition of 5% of the cartons on land fills. The produced energy from the incinerated part is replacing fossil fuel.

To be able to assess and compare the different environmental impacts from the life spans, two methods of valuation (EPS[2] and BUWAL[3]) and one method of normalisation[4] were applied.

For the system which include a recycling of fibres, rules of allocation were applied according to the recommendations from the Nordic project on LCA[5]. This method is explained in Appendix 1.

The environmental indexes obtained for the system of today were set to a 100% for all three methods, and the results from the simulations were seen relatively to the reference system. In order to simplify the curves, only the magnitude of the impacts are shown. Figure 1 shows the results from the calculations.

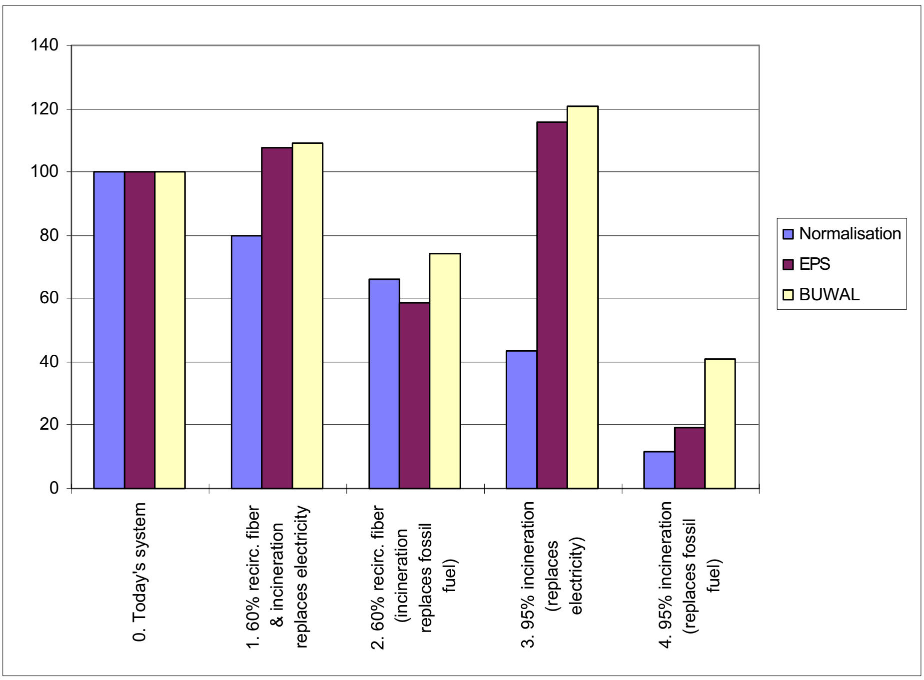

Figure 1. Environmental impacts according to the valuation methods EPS and BUWAL, and the normalisation to Norwegian emissions per capita.

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[2] The EPS Environmental Priority Strategies in Product Design (Steen and Ryding 1992). By this method 5 objects are valued according to the willingness to pay to restore them to their normal status.

[3] The Ecoscarity Method with Norwegian data (Bauman 1992). In this method the emissions or use of resources by a system is multiplied by an index which expresses the difference between the annual load limits set by national environmental regulations and the actual flow of the system in a geographical area.

[4] Normalisation to the yearly Norwegian emissions and energy use per inhabitant.

[5] Nordic Council of Ministers; LCA Nordic 1995.

The figure shows that, according to the three validation/normalisation-models, scenario 2 and 4 give reduced environmental impacts compared to the situation today. For both scenario 2 and 4, the recovered energy from incineration replaces the use of fossil fuel.

In Norway, the average energy source today is hydroelectric power, and the marginal energy source is fossil fuel. According to the results of this study, the optimal environmental solution for the waste treatment of the carton is dependant on whether the energy from the incineration process replaces fossil fuel or not. The recycling of fibre and incineration of the barrier layers may not be environmental favourable compared to the situation of today if this is not the case.

Table 1 gives the trade off situation between the different environmental impacts of the 5 scenarios. The environmental impacts are set to a 100% for the system of today, and the other impacts are seen relatively to the reference system.

Table 1. Environmental impacts for different recycling- and incineration rates of a barrier carton.

	Global climate change	Acidity	Total energy demand	VOC	Waste
0. Today s system - 35% to incineration (replacing hydropower), and 65% to landfill.	100	100	100	100	100
1. 60% recycling, incineration replacing hydropower	136	98	54	97	74
2. 60% recycling, incineration replacing fossil fuel	95	58	54	92	74
3. 95% recycling, incineration replacing hydropower	138	119	19	100	7
4. 95% recycling, incineration replacing fossil fuel	41	24	19	89	7

The table shows that all parameters in the table will be reduced if the energy from incineration replaces fossil fuel. If the energy from incineration replaces hydropower, the emissions of global climate gasses will increase. The acidifying components will also be higher or equal in size if the energy from incineration replaces fossil fuel. Non of the scenarios will give a drastic reduction in the emissions of volatile organic compounds. The amount of waste will of course be reduced for all scenarios, mostly if the carton is incinerated. The optimum system according to these scenarios will of course be dependant of the target of environmental policies and priorities.

To carry out a LCA will always imply to make choices of the valuation models, the time scale and the system boundaries to be applied. The choices faced in the work with this particular case study of the barrier carton were partly linked to the fact of dealing with a renewable material, and partly they were general choices that has to be made in any LCA.

How to deal with valuation of the extraction of raw materials is a vital question dealing with the issue of recycling. Another question is the possible reduction in biodiversity as a result of intensive forestry. These problems are not dealt with in our analysis. The decomposition of materials on the land fill will lead to emissions of global climate gases, and the emissions from the decomposition is dependent on the time scale of the study. The boundary conditions of the use of energy is very vital for the results achieved in this analysis. If the calculations had included that a reduced use of hydroelectric power in Norway would substitute fossil fuel (or nuclear power) in other countries, this would probably lead to a very different solution. The conclusion of this brief discussion is that in order to make a more total evaluation of the question of recycling vs. incineration, more aspects should be taken into account in the calculations, and some more scenarios should be added. In order to take the biodiversity or the extraction of raw materials into account, some criteria have to be developed.

Despite the problems encountered during this LCA study, the study can be seen as an example of how LCA may have a role to play in decision processes where there are many environmental parameters to take into account, and several solutions to choose between.

Appendix 1. Allocation

The LCA-manual recommends to use the method of 50/50 allocation between the first and the last chain in a system of recycling. Figure 2 shows a system with cascade recirculation, where P1 may illustrate the barrier carton which is recycled, and P2 is the product made from the recycled material. In this figure, the product is recycled one more time (P3) before it is thrown in the garbage bin.

According to the 50/50-rule, the system which takes the product out of circulation (here: P3) will be charged 50% of the environmental loads of the production of the virgin material, and will be subtracted half of the loads connected to the recirculation processes. The system which takes the material into circulation (P1) will be subtracted 50% of the environmental loads from the production of virgin materials, and will be added the 50% of the environmental loads from the recirculation process.

The same approach, but with an opposite sign, is applied to the waste-flow of the total system. Half of the waste flow is subtracted from the recycled material (P3) and added to the carton made of raw materials (P1).

The material which is made of recycled material and which goes to recycling after use (P2) will not be allocated any impacts from other products.

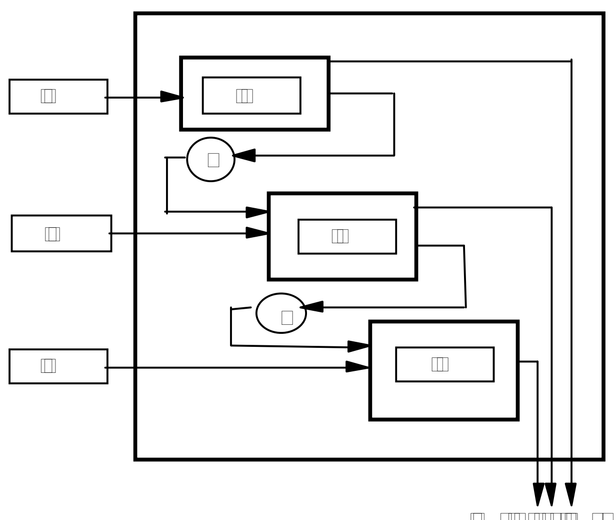

Figure 2. Cascade recirculation.

In the example of the barrier carton, 60% of the carton went to recycling. These 60% were subject to the rules of 50/50 allocation:

- Half of the environmental loads connected with the production of the carton were subtracted and half of the environmental loads connected with the recirculation processes was added.
- Half of the waste flow connected with the discard of the recycled material was added.

Socio-Economic Aspects: General Methods

WOOD FOR ENERGY OR MATERIALS APPLICATIONS - INTEGRATED ENERGY AND MATERIALS SYSTEM OPTIMISATION FOR CO_2 REDUCTION

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Abstract

One of the most challenging environmental problems in coming decades is the emission of greenhouse gases. Especially CO_2 emissions are closely linked to fossil fuel combustion. Renewable biomass like wood can significantly contribute to CO_2 emission reduction. This paper assesses the potential for wood in energy and material applications in Western Europe. Materials production represents approximately 25% of the Western European energy consumption and CO_2 emissions, so materials options like e.g. substitution can significantly contribute to CO_2 emission reduction. It is shown that both energy and materials options for CO_2 emission reduction could encompass all wood that can be grown on future surplus agricultural land. Model calculations for the Netherlands show a significant cost-effective CO_2 emission reduction potential in wood for materials applications. On the other hand, wood applications can significantly benefit from strict CO_2 emission reduction policies. The paper finishes with some recommendations for LCA methodology, based on the experiences with dynamic energy and materials modeling.

Introduction

Wood is widely used for both energy and materials applications. The strong position of wood - used since thousands of years - is in the last two hundred years however challenged by other sources of energy and other materials. On the energy side, fossil fuels (coal, oil and natural gas) have replaced wood as major energy source. In OECD Europe, only 3,6% (2 EJ) of energy is still supplied by biomass. On the materials side alternatives like steel, aluminium and plastics have taken over for many applications. Low price and ample availability of wood alternatives lead to substitution in both areas. As a consequence, our Western society is currently mainly based on fossil energy and non-renewable resources like metal ores. Materials production uses nowadays mainly fossil energy resources (except e.g. paper production). E.g. oil is even embodied in plastic materials.

This trend towards fossil resources may however cease in coming decades because of the greenhouse problem and policies towards more sustainable development. Certain anthropogenic emissions accumulate in the atmosphere. These gases are suspect to enhance the natural greenhouse effect. The result is a global climate change, causing severe damage to environment and society. Almost half of this enhancement is caused by emissions of carbon dioxide (CO_2). Two sources of anthropogenic CO_2 emissions are of primary importance: global deforestation and fossil fuel combustion (1,6 and 5,5 GtC per year, respectively). In Western European countries, the bulk of CO_2 emissions is closely related to the use of fossil fuels for energy applications.

CO_2 reduction studies start thus generally from energy flows. As a consequence, reduction of CO_2 emissions is sought after in the energy area. The system boundaries in this type of studies are defined by final energy consumption. Energy use is considered as final consumption if no energy carriers are produced as output of an activity. Significant amounts of energy are however used for materials production and materials handling. It is for several reasons interesting to approach this type of energy consumption in another way. The first reason is that energy consumption for materials production can be influenced by changes in material and product flows. The significance and cost-effectiveness of this type of options is poorly understood. Vice versa, material flows may be significantly affected if general environmental energy policy instruments like CO_2 penalties are used. The second reason is that some energy carriers are converted into materials (so-called “feedstocks”, e.g. for plastics, elastomers, timber). This energy may be recovered in a later stage, e.g. through waste incineration or recycling. These “feedback” mechanisms require a different approach than traditional energy services. A third reason for a closer look at materials is the sensitivity of energy flows for autonomous shifts in material flows (e.g. more recycling results in less energy intensive primary materials production).

Biomass like wood has a special position from a CO_2 reduction point of view because it can be used in several ways. One extreme is biomass for energy applications in order to substitute fossil fuels. The other extreme is biomass for material applications in order to substitute fossil fuel based materials. Combinations of both applications are also conceivable (Figure 1).

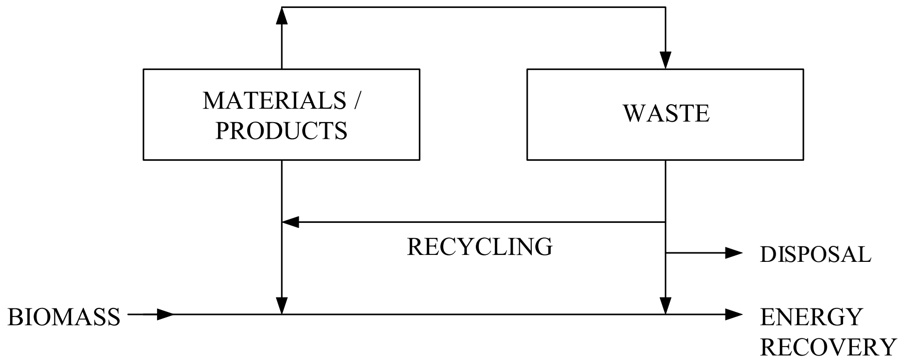

Figure 1. Interaction between biomass for energy and material applications.

Land availability and other environmental constraints limit the potential for biomass crops. It is beforehand unclear, which biomass application should be aimed for in order to achieve maximum CO_2 reduction. It is also unclear, how cost-effective these options are. The first goal of this paper is to assess the potential of wood for reduction of CO_2 emissions in Western Europe, both through energy and material applications. The second goal is to indicate the impact of CO_2 reduction policies on wood use. The third goal is to show that cost-effectiveness of biomass options for CO_2 emission reduction can be studied in a dynamic systems approach instead of in static life cycle analysis (LCA) studies, in order to avoid too optimistic forecasts.

The latter two goals are aimed for in a discussion of a CO_2 emission reduction study for the Netherlands (Gielen & Okken, 1994a). This study is proposes techno-economic and dynamic integrated energy and materials system modeling, based on a long standing tradition in energy systems analysis. Model characteristics are discussed, as they may hold clues how to improve current LCA methodology.

Materials, forests and CO_2

Calculation of CO_2 emissions is largely based on energy statistics (IPCC, 1994). Based on specific CO_2 emissions per energy carrier (coal, natural gas, oil) emissions can be calculated. Biomass, like wood from renewable sources, is an almost CO_2 neutral alternative. Planting, harvesting and treatment takes generally small amounts of fossil energy compared to the energy yield. A forest takes up atmospheric CO_2 to generate wood. If wood is harvested and combusted, it yields no more CO_2 than used for wood generation. Wood plantations show thus zero life cycle impact on the CO_2 balance. Wood can thus be used as CO_2 neutral alternative.

Another often discussed option is the use of (new) forests for carbon storage. The potential of this option is (in the Western European case) however limited because of limited land availability. Substitution of energy and materials seems on the long run a more promising option. Stopping current deforestation abroad can however also significantly contribute to a reduction of global CO_2 emissions. In this paper only renewable (CO_2 neutral) wood resources for energy and materials applications are considered.

The Western European materials system

The importance of the materials system for Western European energy consumption is quantified in Table 1, where all relevant material flows from an energy point of view are listed. The material flow data (column 2) refer to apparent consumption, i.e. flows listed in materials statistics (excluding imports and exports of materials in products).

Gross Energy Requirement (GER) is estimated for the European situation (Table 1, column 3). The GER value equals the energy content of the input materials (feedstock energy), increased by the amount of energy required for recovery and transport of the raw materials and auxiliary resources and for the manufacture of the intermediate and final products. All energy is traced back to primary energy and accumulated. E.g. for electricity generation, an average efficiency of 40% is assumed. In case that raw materials are also energy carriers (e.g. plastic and wood) the GER-figure is usually dominated by the feedstock energy. Both GER values for primary production from natural resources and from waste materials (recycling) are listed. The listed GER-values include both fossil and biogenous feedstocks. Table 1 shows that GER values for materials recycling are considerably lower than for primary materials production. The fourth column in Table 1 shows the fraction primary production and the recycling fraction. The recycling fraction is in this case defined as the fraction of the listed material flow, derived from waste materials. The last column: total energy consumption can be calculated by multiplication of columns 2, 3 and 4 for primary production and recycling, respectively, and subsequent addition. The total energy consumption for materials production in column 5 is 12.9 EJ. This figure can be compared to a top-down analysis of European industrial sectorial energy consumption for materials production, shown in Figure 2 (15.8 EJ, excluding energy from biomass). Because not all material flows are included in Table 1, the energy consumption from the top-down calculation is somewhat higher than the Figure from the bottom-up calculation.

Table 1. Materials consumption + energy equivalent (Western Europe 1990, food production and energy recovery not considered).

Material	App. consumption [Mt/year]	Primary/Recycling GER[1] [GJ/t]	Primary/Recycling fraction [%]	Total Energy [PJ/year]
Metals				
Aluminium	6.2	175/5	70/30	770
Copper	3.2	100/5	60/40	200
Lead	1.0	25/4	60/40	17
Steel[2]	138.6	23/5	60/40	2200
Zinc	2.0	25/4	70/30	37
Other materials	1.0	50/10	50/50	30
Synthetic organic materials				
Bitumina	17.1	44/-	100/0	750
Elastomeres	2.9	70/5	95/5	190
Lubricants	5.9	55/5	100/0	325
Paint	5.0	45/-	100/0	225
Polyolefines[3]	13.0	65/4	95/5	800
Polystyrene	2.4	70/4	90/10	150
PVC[4]	5.2	55/4	80/20	230
Oth. plastics	5.0	80/5	90/10	360
Surfactants	7.7	65/-	100/0	500
Other detergent agents[5]	15.0	40/-	100/0	600
Solvents[6]	3.0	50/-	100/0	150
Inorganic materials				
Ammonia[7]	11.5	30/-	100/0	350
Chlorine	10	15/-	100/0	150
Na(OH)	10	15/-	100/0	150
Other inorganic				pm.
Natural organic materials				
Paper/Board	57.1	40[8]/10	65/35	1685
Wood[9]	80.0	25/2	95/5	1910
Other fibers[10]	2.8	40/5	75/25	90
Other natural organic				pm.
Ceramic materials				
Bricks	65.0	3/-	100/0	200
Cement	187.0	4/0.3[11]	90/10[12]	680
Glass	24.0	7/6	60/40	160
Other ceramic[13]				pm.
Total				12909

1 Assuming 40% efficiency in electricity production; includes feedstock energy & renewables
2 Recycling refers to EAF production
3 Predominantly polyethylene and polypropylene
4 PVC = Poly Vinyl Chloride
5 Estimation, based on surfactant consumption. Includes e.g. zeolites, TAED, borax, enzymes

[6] Excludes solvents in paint
[7] Predominantly used for nitrogen fertilizers
[8] Average for different paper grades
[9] Includes all wood products excl. paper and board
[10] Natural fibers: Wool, cotton, viscose etc.
[11] Portland cement/blast furnace cement
[12] Linked to primary steel: 0.25 t blast furnace slag per t primary steel, thus annually 138.6 ´ 0.6 ´ 0.25 = 20.8 Mt blast furnace cement (maximum estimate)
[13] E.g. sand-lime bricks

One should note that product assembly, freight transportation and waste handling may add another 30% to the energy consumption in the materials system (see Figure 1). These results show clearly that industrial energy consumption is predominantly energy consumption for materials production. The total energy consumption for materials production represents at least 24% of total Western European energy consumption (54.1 EJ). As industrial energy is mainly fossil fuel based (Figure 2), significant CO_2 emissions are related to this energy consumption. As a consequence, materials policies can significantly contribute to Western European CO_2 emission reduction.

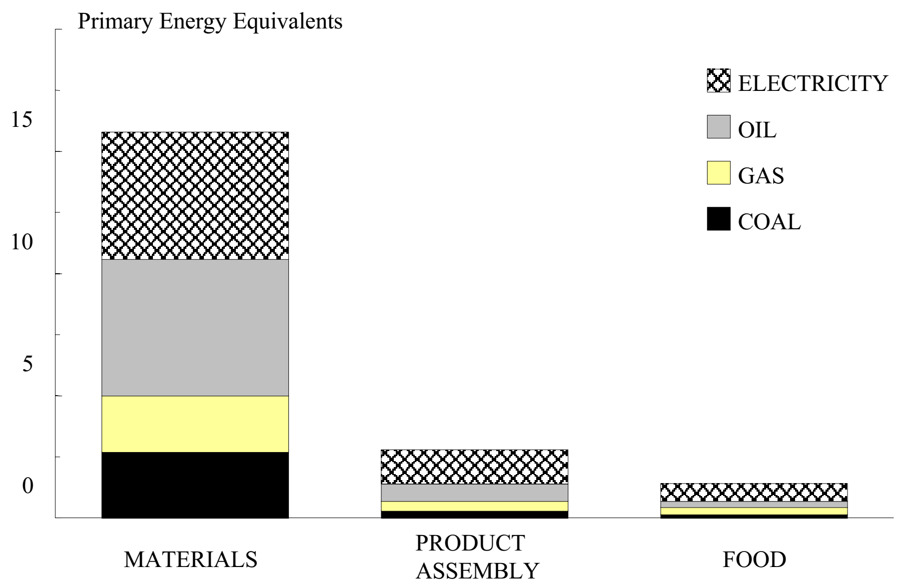

Figure 2. ***Breakdown of industrial energy consumption in Western Europe, 1990 (IEA/OECD, 1993).***

Table 1 shows that wood and paper production are important from an energy and materials flow point of view. Only steel production requires more energy. Wood is thus still widely used. The majority of European forests are - to some extent - used for wood production. However, in future significant agricultural areas may become available due to food crop surpluses and decreasing subsidies. This surplus area can be used for additional energy or material crops.

The assessment of biomass options for CO_2 reduction gives rise to several questions:

- how much land will become available ?
- how much biomass can be grown on this land ?
- which biomass type should be used ?
- should biomass be used for energy or for material applications ?
- which materials or energy carriers can be substituted by wood ?
- what would be the energy/CO_2 profits of such substitution ?
- what would be the cost of such substitution ?

These questions will be discussed in the following paragraphs.

Wood for energy applications

Western European usable land area amounts to 276 Mha (Table 2). Significant agricultural land areas will become available in coming decades. How much of this "usable" land could be put to energy or materials cropping will depend on policies regarding agricultural subsidies, food surpluses, energy self sufficiency and rural economics. Estimates for the period beyond 2000 range from 10 to 15 %.

Table 2. Western European land availability (Hall, 1994).

Type	[Mha]
Cropland	92
Permanent pasture	63
Forest & woodland	121
Total useable land	276

Several crop types can be used. Energy crops can include currently well known agricultural crops (e.g. cereals, rapeseed), new agricultural crops (miscanthus, hemp, sweet sorghum) or wood type crops (e.g. poplar, willow). The best choice is currently unclear. It depends on e.g. yields, costs and product markets. Energy markets can be divided into electricity, heat and transportation fuels. Generally speaking, biofuels for transportation applications are considered the most expensive option (IEA, 1994). On one hand, production costs (per GJ fuel) are high, on the other hand production results in significant fossil fuel consumption and relatively small CO_2 savings. The most favourable option seems currently wood or miscanthus for gasification and subsequent electricity generation, preferably operated in CHP (combined heat and power generation) mode. Only wood type crops for electricity generation will be considered further.

Assuming an average yield of 10 t oven dry matter (ODM) per hectare and 17 GJ per t ODM, biomass could additionally contribute 4,7 to 7,0 EJ per year (276 to 410 Mt ODM per year) to Western European primary energy consumption, this equals 8,7 to 12,9 % of current Western European primary energy consumption. These figures should be compared to current biomass use for energy purposes (2,0 EJ). The potential for energy crops is thus limited. This is an important fact: as a consequence, biomass should be used as effectively as possible in order to achieve maximum CO_2 reduction. As conversion efficiency towards electricity for future BIG/STIG plants (biomass integrated gasifier/steam injected gas turbine) is in the same range as for coal fired power plants, biomass energy could replace similar amounts of fossil energy.

Wood for material applications

Current Western European roundwood production amounted in 1990 to 317,2 Mm^3. Assuming average density of 0,55 t/m^3, this equals approximately 174,7 Mt roundwood. Net consumption amounted to 185,5 Mt roundwood, so there exists a small net import. These figures are very approximate and disguise significant trade in roundwood of greatly different values, e.g. pulp, sawnwood, paper, board etc.

If wood is grown for material purposes, yields will generally be lower than for energy purposes. This depends off course on the type of application; for fibers, yields may reach similar figures than for energy crops. For sawnwood however, other wood qualities are required, with generally significantly lower growth rates (50% less). In this first assessment, a 50% lower yield for materials crops than for energy crops is assumed. The additional potential is thus 140 to 205 Mt roundwood.

As production and consumption of Western European roundwood are currently more or less balanced, future Western European additional wood crops for material applications can only be used if:

- demand for wood products increases (additional product demand)
- wood substitutes other materials
- wood is exported

The latter option is beyond the scope of this study. Concerning increased wood consumption, highest growth figures are forecasted for paper and sawnwood. Growth estimates for Western European consumption for the period 2020-2050 range between 30 and 50% (both wood and paper products) (Arnold, 1993). This leaves 70 to 165 Mt potential roundwood that can be applied for materials substitution. One could argue that wood requirements for increasing product demand should also be considered on the case of energy crops. It is generally neglected in studies concerning energy crops, but seems important for proper assessment of future biomass potentials.

The potential for substitution of other materials depends on future developments concerning product demand and materials intensity of products (materials intensity refers to the amount of materials per functional unit, e.g. kg paper/bag). Generally speaking, substitution seems primarily feasible in the area of building materials because this is by far the largest market from a materials point of view. Wood and other biomass can also be used for feedstock purposes for plastics, lubricants, solvents etc. (feedstocks are energy carriers that are embodied in materials). E.g. lignin fractions, currently incinerated in pulp mills, may be used for feedstock applications or may even become sources for new types of 'bioplastics' (Faix, 1992).

In order to show the magnitude of potential future materials applications, building applications and feedstocks will be discussed in more detail. Wood in buildings can replace concrete, bricks and steel. The ratio of weights of wood alternatives (ovendry weight) to serve in place of several important non-wood products in building applications is shown in Table 3.

Table 3. ***Weight ratio for wood alternatives for non-wood products (Koch, 1992; Meier et.al. 1990; Sikkema & Nabuurs, 1994; Gielen & Okken, 1994b).***

Alternative	Weight ratio [t wood/t subst.]
Wood stud in place of steel stud	1.90
Treated wood post in place of steel post	2.10
Plywood siding in place of brick veneer	0.05
Wood wall construction instead of double layered brick wall	0.20
Wood floor in place of cement in concrete slab floor	0.50
Wood instead of cement in traditional buildings (average)	0.50
Wood parquet instead of polyamide carpet	1.90
Wood furniture instead of steel	1.00
Wooden pallets instead of plastic pallets	1.40

Wood can of course not replace all building materials. E.g. in buildings with more than 4 floors, wood cannot be applied due to structural constraints. A first general assessment of potential wood applications is shown in Table 4. The fraction in the third column contains the materials fraction used for building applications

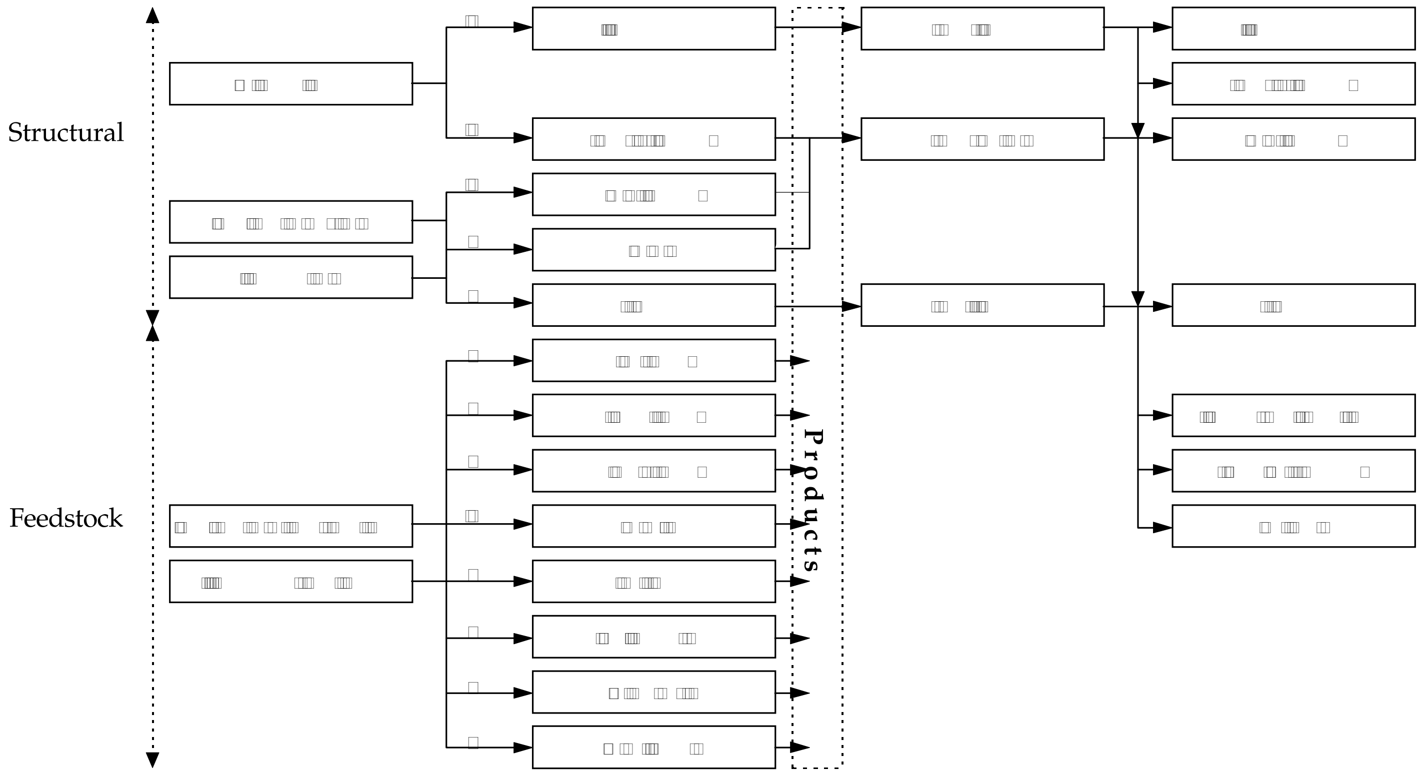

Figure 3. Potential for additional biomass applications through substitution (excluding materials substitution in packaging; figures indicate potential additional biomass inputs in Mt/year, 2030).

multiplied by the fraction of building applications where substitution seems feasible within the time horizon of 2030. The total maximum additional wood application potential, 112.8 Mt wood, is in the range of potential additional roundwood yields in case sawnwood yields are maximised (70 to 165 Mt).

Table 4. ***Potential for additional wood applications in buildings (Western Europe, 2030).***

Substitute [Mt/year]	App. cons. [-]	Fraction [t wood/t subst.]	Wood substitute [Mt. wood/yr]	
Brick	65	0.80	0.2	10.4
Cement	187	0.50	0.5	46.8
Steel	139	0.20	2.0	55.6
Total				112.8

Potential materials substitution by biomass in different areas can be estimated for different material applications. Figure 3 lists a first estimate that includes building and feedstock applications. The total additional potential biomass input for materials production in 2030 is estimated at 166 Mt/year. One should emphasize that this is only a first general analysis. E.g. additional recycling and cascading (the right part of Figure 3) is not quantified.

Substitution of energy or materials: problems and pitfalls

The analysis in the preceding two paragraphs showed that both energy and materials applications could encompass all the biomass from surplus Western European agricultural land area. The primary driving force for such substitution are strict CO_2 reduction policies. The question to be answered is thus: how far can CO_2 emissions be reduced by energy and materials substitution ?

If only biomass flows are considered, the choice seems straightforward: yields are twice as high for energy crops. If fossil fuels for power plants are replaced, significant CO_2 reduction can be achieved. The result is a favourable CO_2 balance for the biomass option, as coal is the fossil fuel with the highest CO_2 emission per GJ electricity (GJel). The problem with this comparison is however the large number of competing options in this field (Table 5). Because of the large number of competing, relatively cheaper, CO_2-free electricity generation options, the future for biomass for power generation seems not quite so clear. E.g. calculations for the Netherlands show that biomass crops are - in the Dutch case - not the most cost effective option for CO_2-free power generation, and waste biomass is considered first for power generation (Gielen & van Doorn, 1995).

Table 5. Some competing options for CO_2-free electricity generation (Western Europe, situation 2030).

Type	Cost [NLG/GJel][1]	Potential [% of el demand]
Coal (reference)	22	
Biomass	40	25
Coal + CO_2 storage	40	75
Gas + CO_2 storage	35	75
Hydropower	25	20
Nuclear	20	75
Photo Voltaic	80	50
Wind	30	20

[1] NLG = Netherlands Guilders

In case of materials production, similar problems exist. The different environmental impacts of primary materials production and recycling are well known to LCA practitioners. The CO_2 emission for steel recycling is approximately one fourth of the CO_2 emission for primary steel production. There is thus a large difference which steel type is used as reference option to be substituted by wood. Considering CO_2, emissions related to electricity inputs are also of primary importance. E.g. in the case of primary aluminium production, CO_2 emissions can range from 3 t/t aluminium for CO_2-free electricity to 15 t/t aluminium for coal fired power plants. Because of these strong interactions between the energy and the materials system, an integrated approach is required for proper assessment. Such an approach is shown in the next paragraphs.

Integrated optimisation: the modeling approach

The importance of wood from an energy and CO_2 point of view is quantified in the preceding paragraphs. The next question to be answered concerns the cost effective potential for reduction of CO_2 emissions through wood for energy and material applications. This will be shown in a case study on CO_2 reduction in the Netherlands.

In order to study the interaction between the energy and the materials system, an existing model for the Dutch energy system has been enlarged. The energy system is modeled within MARKAL. MARKAL, an acronym for MARKet ALlocation, is a dynamic linear programming (LP) energy system optimisation model which has been developed in an international effort at the beginning of the 80's (Fishbone, 1983). The model is used in IEA/ETSAP cooperation (International Energy Agency/Energy Technology Systems Analysis Programme), where eleven

OECD countries and the EU together study reduction of greenhouse gases (see e.g. Kram, 1993). MARKAL calculates the least-cost system configuration that satisfies externally defined demand for final energy services, while taking environmental policy goals like CO_2 emission targets into account. This optimised energy system is developed from a database of supply, conversion and demand technologies. Each technology is characterised by technical, financial and environmental parameters. The MARKAL model for the Netherlands contains a database with approximately 500 energy supply and demand technologies.

Modeling material flows in an energy model requires some fundamental changes in the model structure, due to different characteristics of energy and materials. The materials system consists of materials and product life cycles. Natural resources are extracted from the environment and converted into useful materials. These are used for product manufacturing. The product is used and beyond the product life, waste materials are released. Waste materials can - contrary to waste energy - often be recycled into materials. The other interesting difference between energy and materials is the time lag between materials use for product manufacturing and waste materials release beyond product life. In the case of buildings, the time lag may be several decades or even hundreds of years. Similar time lags do not occur in the energy system. These two features can explain many differences between energy system and materials system dynamics.

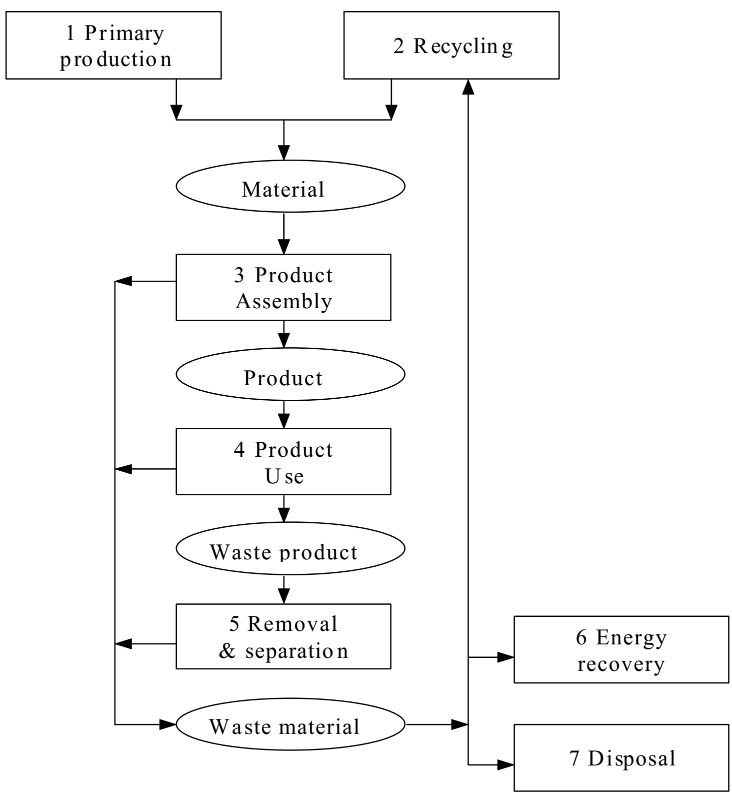

Figure 4. Materials system model structure (Gielen & Okken, 1994a).

Figure 4 shows the general materials system model structure. Four types of material flows are discerned (materials, products, waste products and waste materials). Seven types of technologies are discerned, representing the whole life cycle. As CO_2 reduction is the issue to be studied, the materials system is limited to materials and products that are important from a CO_2 point of view. This includes obvious materials like steel, aluminium, plastics and cement, but also less obvious materials like compost, tropical hardwood, fertilizers and detergents (Gielen & Okken, 1994c). A large effort was put into characterisation of 29 materials, 20 product groups and 30 waste materials and some 200 processes which link material flows.

CO_2 reduction options in the materials system include e.g.:

- industrial energy savings, based on new technologies;
- CO_2 removal from industrial plants and storage;
- reduction of materials consumption (e.g. reusable packaging);
- materials substitution;
- biogenous feedstock materials;
- improved waste collection and separation systems;
- waste recycling, cascading and energy recovery.

Maximum CO_2 emission levels are exogenously defined for the whole (energy and materials) system. CO_2 constraints for emission reduction cases follow linear paths from 2000 to 2030 and then stabilize. Reduction percentages imposed for the year 2030 include stabilisation (0%), 20%, 40%, 60% and 80%, compared to the emission in 2000. There is no current policy goal in the Netherlands for CO_2 emissions beyond 2000, so the calculations have an exploratory character.

A case study for the Netherlands

Figure 5 shows the model results for the integrated energy and materials system concerning CO_2 emissions in the base-case for a high growth scenario (no CO_2 reduction targets). The materials system is responsible for approximately one third of the CO_2 emissions from the energy system. Emissions from the materials system (M) are stabilised in time, while total emissions from the energy system (E) increase. On one hand, this stabilisation is caused by improved materials efficiency and recycling; on the other hand dematerialisation plays an important role. Demand for traditional products like cars and buildings is getting saturated. With increasing wealth, people start to buy more luxurious goods and services with lower materials content. The mechanism of dematerialisation is a complex of technological developments and life-style factors. The subject is however not further elaborated in this paper.

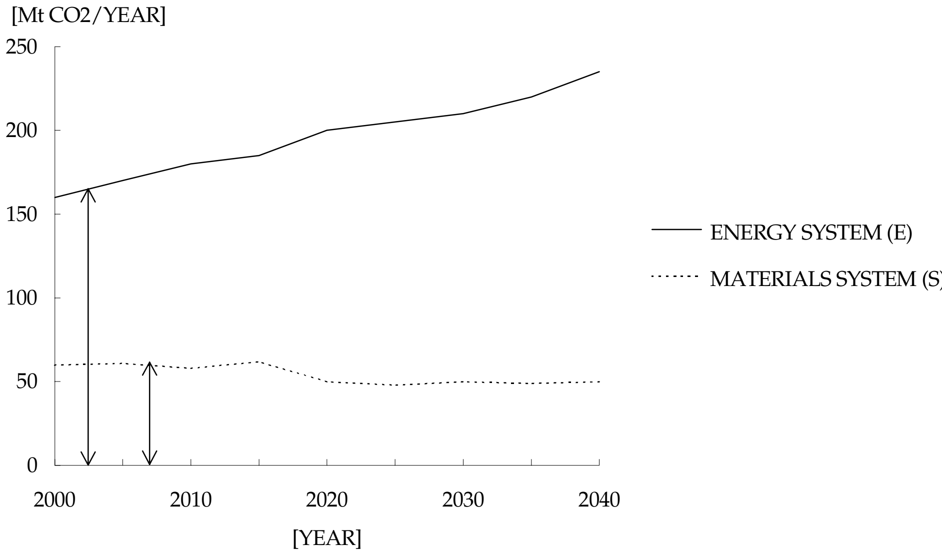

Figure 5. Base case CO_2 emissions for the energy system (E) and the materials system (M) (Gielen & Okken, 1994a).

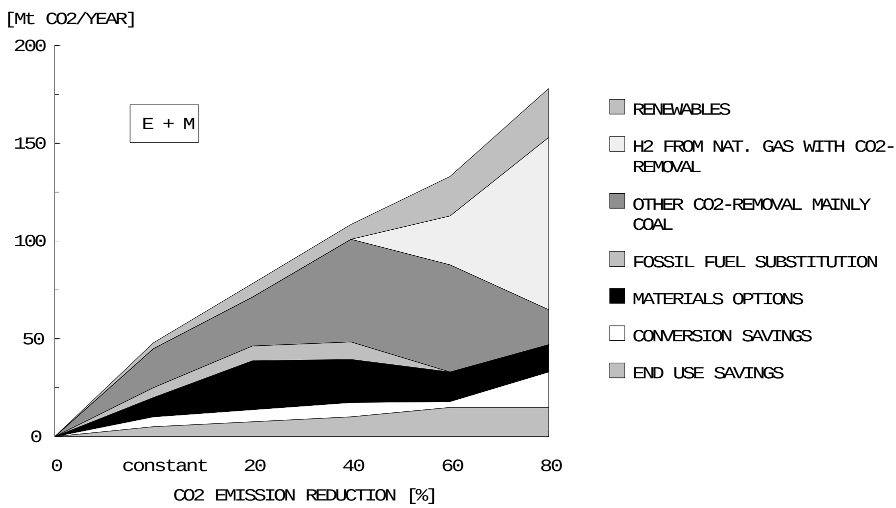

Figure 6. Emission reduction allocation for the integrated energy and materials system E+M (year 2030) (Gielen & Okken, 1994a.

Figure 6 shows the contribution of various emission reduction options in the integrated energy and materials system as calculated by the model. On the energy supply side, potential for renewable energy is limited due to climate and geographic conditions. Within 15 years it is expected that the Netherlands will have capacity for storage of CO_2 in depleted natural gas fields or aquifers allowing for CO_2 removal options. Such options have been considered for electricity generation and for synfuel production (e.g. hydrogen). CO_2 storage plays a crucial role for achieving significant emission reduction at acceptable costs. At lower emission reduction levels, CO_2 is removed from power plant flue gases. At higher emission reduction levels, synfuels are introduced and a "hydrogen economy" develops. As the Dutch energy system already depends on natural gas to a large extent, the potential for fuel substitution (e.g. coal to natural gas) as a CO_2 reduction option is limited. On the energy demand and conversion side, significant savings are still achievable, e.g. through better insulation of buildings. Shifts in the transportation sector prove to be very costly, while the potential for industrial shifts (energy efficiency improvement) is limited. The potential for demand side CO_2 reduction is however limited, because many options are already included in the baseline because of their cost-effectiveness.

How is CO_2 emission reduction introduced in the materials system? As a result of CO_2 reduction targets, materials in products are substituted. Figure 7 shows shifts in material use caused by setting high CO_2 reduction targets. Two main shifts occur in the construction and transportation sectors. Traditional brick/concrete buildings are replaced by wooden skeleton buildings. Energy consumption per tonne for brick and cement production is relatively low, the relatively high CO_2 emission for traditional buildings is caused by large amounts of materials required per house and because of inorganic CO_2 emissions from cement production. In the transportation sector, production of cars and trucks shifts towards use of more aluminium. Fuel savings due to lighter constructions is in this area the main drive. The net result of materials substitution is a decrease in cement use, while use of wood and aluminium increases beyond 2015. Steel and plastics remain almost unaffected.

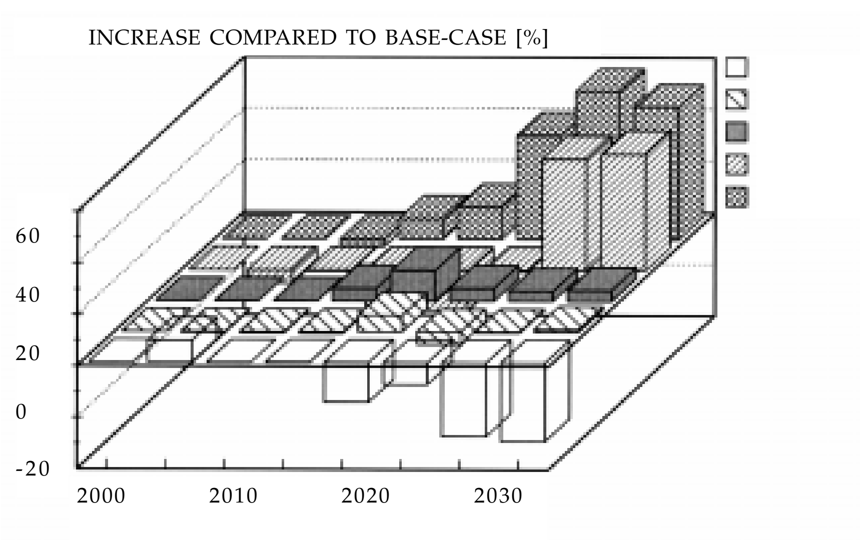

Figure 7. ***Shifts in materials consumption due to CO_2 emission reduction (60% reduction case). (Gielen & Okken, 1994a).***

These results prove to be very sensitive to assumptions concerning assembly costs for different product options. The impact of 60% CO_2 reduction on product life cycle costs is generally below 10 %. The uncertainty range in future production costs is however in the same order of magnitude as the impact of CO_2 reduction on life cycle costs. This sensitivity problem occurs for most products.

Shifts in the materials system occur because it is in some cases cheaper to reduce CO_2 emissions in the materials system than to reduce emissions in the energy system. This results in a significant decrease in CO_2 emission reduction costs shown in Figure 8. If only the energy system is considered for emission reduction, significant costs arise in 2010 because existing power plant have to be discarded before the end of their lifetime. This can be avoided if additional reduction options in the materials system are taken into account. But apart from the large cost reduction in 2010, long term marginal CO_2 emission reduction costs decrease by NLG 50-100, a reduction by approximately 30 % (Marginal reduction costs represent the most costly CO_2 reduction option applied to comply with emission reduction goals). In LP models like MARKAL additional emission reduction options, like i.c. materials system options, will always result in equal or lower emission reduction costs. It is the extent of cost reduction that is a new and significant result.

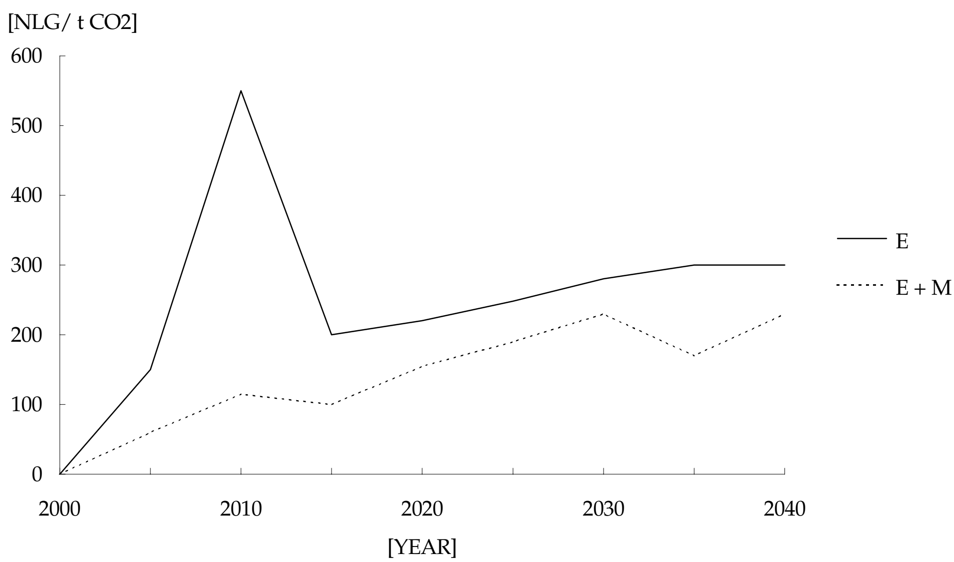

Figure 8. ***Marginal CO_2 reduction costs for the energy system (E) and the integrated energy and materials system (E+M) (60% reduction case) (Gielen & Okken, 1994a).***

Other options in the materials system are e.g. "design for recycling", extended product life time, reusable products (e.g. packaging) and decreased materials intensity of product services because of increased materials quality. These options were not included in this study, as they require a totally different approach. The results show that the potential for CO_2 emission reduction in the materials system is in the same order of magnitude as internationally accepted technological reduction options like renewable energy or electricity conservation (Okken & Ybema, 1994). However, research in this area is still in its infancy and the idea is new to many policy makers and researchers.

Conclusions

Biomass can be used as CO_2-neutral alternative for both energy and materials applications. The use of biomass can significantly contribute to a reduction of Western European CO_2 emissions. Wood seems a good option, but other agricultural crops may be viable alternatives. It is still unclear if biomass should be used for energy or materials applications for achievement of maximal CO_2 reduction. Both applications can encompass all potential additional wood from surplus agricultural land. The significant CO_2 emission reduction potential for bioenergy is well known for many years. Materials substitution can however also significantly contribute to CO_2 emission reduction, as approximately one fourth of Western European energy demand (and CO_2 emissions) can be attributed to materials production. Current LCA methods are however not suited for comparison of bioenergy and biomaterials options because of strong dynamic interactions. For this reason, an integrated energy and material system approach is required. The MARKAL model is suited to study the energy and materials interaction.

Results for the Netherlands show that, if significant CO_2 emission reduction is aimed for, both the energy and the materials system change. The calculations indicate increased use of aluminium and wood, while use of steel and cement decreases. This is caused by changes in the construction and transportation areas. Material options should be studied in more detail because marginal long-term CO_2 reduction costs are for the Netherlands reduced by 30% in the case of integrated (energy and materials system) optimisation, compared to earlier studies for the energy system alone. Moreover, options within the materials system are often truly sustainable (contrary to e.g. CO_2 storage), an important feature supporting current long term policy strategies. The calculations are off course limited to energy and CO_2 emissions, consideration of other environmental problems may change the optimal solution.

The modeling study for the Netherlands shows several aspects relevant to LCA practice:

- The reference situation may change in time (e.g. CO_2 intensity of electricity production). In such cases LCA, based on current process characteristics, is less suited for assessment of long life products, e.g. building materials.

- Allocation problems (e.g. co-production of wood products, recycling allocation) can be avoided if an integral systems approach is used. The drawback is off course the increased data requirement.
- Financial data should be included in the valuation in order to avoid costly improvements with little environmental progress.
- Policy goals for certain emissions can change in time. If such policy goals are used for valuation purposes, a dynamic approach is required, especially for long life products.

It may be useful to consider such aspects in future progress discussions on LCA. Energy system studies may hold some clues how to improve current LCA practice.

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FOREST AND FOREST PRODUCTS: THE CHALLENGE FOR A BETTER CARBON BALANCE

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Abstract

Until now studies on the greenhouse effect paid much attention to carbon fixation by forests, while the entire CO_2-cycle of forest and forest products remained underexposed. Utilization of wood products instead of energy-intensive materials (plastics/steel) and fossil fuels (coal) proves to play an important role as well. The effect of utilization is even greater than that of fixation. In all, additional forests together with multiple use of trees can contribute substantially to the reduction of CO_2 emissions. The contribution can run from 5.3 ton CO_2/ha/yr for a mixed forest of oak/beech to 18.9 ton CO_2/ha/yr for energy plantations (poplar).

1. Introduction

The greenhouse effect is a problem acknowledged worldwide. The increasing concentration of greenhouse gases in the atmosphere (carbon dioxide, methane, nitrogen oxide and others) may in time lead to an unwanted temperature rise. This may threaten the world's climate. One of the largest problems of the greenhouse effect is the burning of fossil fuels by which large amounts of CO_2 (the primary greenhouse gas) are released into the atmosphere. Forests and the use of wood contribute to the fight against the greenhouse effect in three ways:

1. Carbon sequestering (during their growth trees convert CO_2 into timber)
2. CO_2 avoidance through substitution by wood of energy-intensive materials such as plastics, aluminium and steel. Processing timber uses relatively little energy (fossil fuels). After use it can easily be reused, e.g. as particle board.
3. CO_2 avoidance by using timber instead of fossil fuels for generating energy. When recycling has become technically or economically impractical, wood may be used for energy purposes. The same is valid for timber from special energy plantations. Only the previously sequestered CO_2 will be released when burning the woody material. This makes the use of timber 'CO_2 neutral'.

In 1989 the CO_2-emissions in the Netherlands amounted to 183 million tons. These increase by 3.5 million tons annually. The Dutch government is striving for stabilization with respect to the 1989 emissions level. This corresponds to a reduction of 21 million tons CO_2 by 1995.

1.1. Sequestering or avoiding?

Recently a number of reports are published concerning the carbon sequestering potential of various forest types. These studies primarily examine carbon sequestration in biomass (the tree), soil and timber products. Findings suggest that long rotation forests provide a greater contribution than short rotation forests (Table 1, No. 1).

Besides the average carbon sequestration by trees and in timber products, an important CO_2 reduction effect is created through substitution for nonwood products (product substitution) and fossil fuels (fuel substitution). This CO_2 avoidance was included in the SBH-rapport.

Table 1. Potential contribution to CO_2 reduction (in tons CO_2/ha) of several forest types.

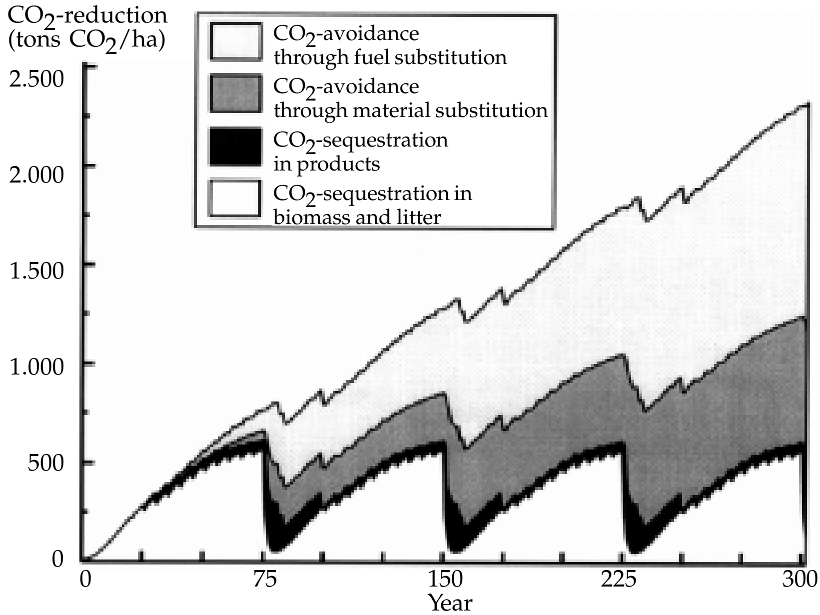
	Oak/Beech	Spruce	Poplar 15 year	Poplar 5 year
1. CO_2 fixation in biomass, humus and products (average)	432	394	104	-106*)
2. CO_2 avoidance through replacement of non-timber materials	182	784	653	0
3. CO_2 avoidance through replacement of fossil fuels	966	1289	1560	5788
TOTAL CO_2 reduction in 300 years	1580	2467	2317	5682

*) Including processing energy of fertilization (0.44 ton CO_2/ha/yr)

Substituting wood for plastic, aluminium and steel leads to an important reduction in emissions. This is because the production of wood materials uses far less fossil energy than the mentioned alternatives. The effect is most evident in saw and packing timber products, such as frames, construction timber and pallets. Norway spruce is a forest type that produces relatively many saw logs and packaging timber products (Table 1, No. 2).

The greatest contribution to CO_2 reduction, however, results from substituting wood for coal in energy production. This is especially true for energy wood plantations (short rotation poplar), from which all wood produced, such as increment, is used as fuel (Table 1, No. 3).

The effects of both product and fuel substitution are repeatable. During cultivation, harvest, use and renewed cultivation, no additional CO_2 is released into the atmosphere. The average sequestration clearly has a once-time effect, because in time the CO_2 is released again, either through decay or through combustion (Figure 1).



Source: Stichting Bos en Hout, Wageningen, The Netherlands

Figure 1. ***Total CO_2 reduction effect of Norway spruce stand having a rotation of 75 years (tons CO_2/ha) - Carbon sequestration in biomass, litter and products is subject to fluctuations during every rotation. An average sequestration, which reaches a constant value of 394 tons CO_2/ha after several rotations, was used for calculations in the text.***

Table 2. ***Contribution by forest type to 1995 goal for national CO_2-emission reduction - National CO_2-emissions were 183 million tons in 1989. Emissions increase 3.5 million tons annually. 1995 goal: Stabilization with respect to 1989 corresponds to a reduction of 21 million tons CO_2.***

	Oak/Beech	Spruce	Poplar 15 year	Poplar 5 year
Annual reduction (in tons CO_2/ha)	5	8	8	19
Reduction per 100,1000 ha (in tons CO_2)	530000	820000	770000	1890000
Contribution to policy ’95	2.5	3.9	3.7	9.0

2. *Methodology*

In the SBH study CO_2 balances of long rotation forests (oak/beech, 150 years) were compared with those of short rotation forests (poplar, 5 and 15 years), and supplemented with those of Norway Spruce, a wood species ideal for recycling.

The contribution to CO2 emissions reduction (see Table B) proves to be substantial. Based on an additional forest extension of 100,000 ha, a mixed oak/ beech forest (150 years) contributes 2.5% of the Dutch government's reduction goal of 21 million tons emissions by the year 1995. Short rotation forests of poplar (5 years) can contribute 9%.

2.1. Forest types

Calculations were made for four forest types (see Table 3). An average tree-species specific increment was assumed. The average CO_2 sequestration in the tree itself and in the upper soil layer (litter) of each forest type over a 300 year period was modelled. Sequestration in the stable humus was not considered, because this factor is greatly dependent on soil types and previous use of soil (e.g. agriculture). In the Netherlands the extra fixation by afforestation amounts to a small quantity. Earlier research showed that the soil of former farmland retains only 66 tons CO_2 when afforested. This is a negligible contribution compared to the total CO_2 reduction prospects. (See Table 1).

Table 3. Important characteristic figures of considered forest types.

	Oak/Beech	Spruce	Poplar 15 year	Poplar 5 year
Rotation time (yr)	150	75	15	5
Number of rotations in 300 yr	2	4	20	60
Mean increment (m^3/ha/yr)	5.4	11.5	15.9	29.5
Density air dry (kg/m^3)	700	460	450	450
Amount of carbon in dry matter weight (%)	50	50	50	50

2.2. Sequestration of CO_2 in tree and soil

With each rotation, forests 'produce' wood that becomes available during thinning and during the final felling at the end of the cycle. Most of the wood ends up being used outside the forest as industrial wood. Another part of the felled trees remains in the forest as dead wood. This wood ends up in the litter layer and breaks down during decomposition to CO_2 and water. Thus the fixed CO_2 in wood is gradually released into the atmosphere.

No wood is left behind in short rotation poplar forests. The entire above-ground biomass (the trunk including the branches, but excluding the leaves) of this forest is destined to serve as fuel for energy production. Thus, hardly any sequestration occurs in the litter layer. Removal of the trunk and branches also means the disappearance of nutrients. Fertilizing compensates for this effect. The processing energy of the fertilizer (0.44 ton CO_2/ha/yr) such as lime and K_2O is subtracted from the net sequestration. Total sequestration as a result has a negative value.

2.3. *Sequestration of CO_2 in products*

Depending on the diameter and tree species, harvested forest products are assigned to be used as fuel wood, pulp wood, wood based panels, packing or sawn timber. The research model assumes optimal utilization of the available amount of raw material. This means sawing residues (bark, sawdust, chips, etc.) are assigned to the most durable uses, like chipboard, paper and cardboard, or when not possible, to fuel.

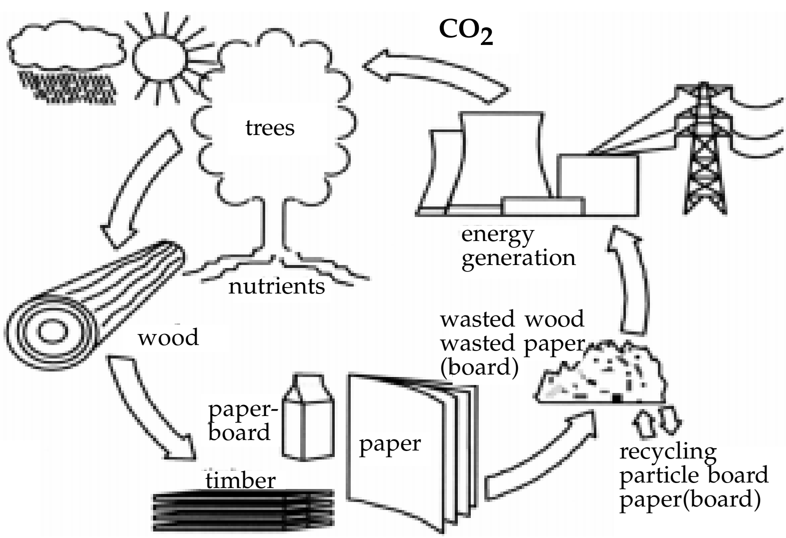


Figure 2. All wood and timber products end at the stage of energy-generation.

Fuel wood is delivered to the power station in chipped and dried form. Assumed is the possibility to allow the wind to dry the wood in the forest naturally (to a maximum moisture content of 15%). All timber products run through a so-called 'cascade model' (Figure 2). Where possible this calls for wood to be reused at the end of its technical life span. In this model packaging material and other timber products will be reused for chipboard or paper. Ultimately, when written off or replaced, particle board and waste paper are used for energy generation. Thus all sequestered carbon will again be released to the atmosphere as CO_2.

2.4. CO_2 avoidance through material substitution

The first reduction of CO_2-emission occurs when wood replaces non timber products. Consideration is made of the use of fossile fuels. An important factor is the energy applied during production and transportation of raw materials, semifinished products and finished products. Net energy applied is calculated in the model. This means that remnant wood is utilized for drying other wood. Some production processes are therefore CO_2/energy neutral. It is assumed that mineral oil is the only fossil fuel used in this application.

There are no material substitution possibilities for paper and chipboard. Although, the production of paper and chipboard require energy. The required processing energy of each is therefore adjusted with the combustion values of wasted paper and chipboard (fuel substitution).

2.5. CO_2 avoidance through fuel substitution

Secondly, the application of energy wood, remnant wood, waste wood and waste paper for energy purposes is considered. Timber products (in contrast to fossil fuels) are CO_2 neutral. Fuel wood does produce carbon dioxide emissions, but the emissions occur within a closed cycle. After all, wood originates and grows by extracting an equal amount of CO_2 from the atmosphere. In this study, a comparison was made with coal, one of the most used fossil fuels for generating electricity in the Netherlands. This comparison is the most realistic, because electricity producers have serious plans to use wood in coal-fired power stations in the short term.

Conclusions

- Studies on CO_2 reduction pay too much attention to sequestering of CO_2 in biomass, soil and products. Thus, the total CO2 cycle of forests and forest products remains underexposed. Utilization of wood (multiple use of products and energy-generation) proves to play an important role. The influence on the CO_2 balance (avoidance through product substitution and fuel substitution) is even greater than carbon sequestration by trees.

- Forests and the multiple use of wood (including energy-generation) can contribute substantially to the reduction of CO_2 emissions. The contribution to the Dutch government's policy (reduction of the annual emission by 21 million tons) can run from 2.5% for a mixed forest of oak and beech, to 9% for short cycle (5 years) poplar. These percentages are based upon an additional 100,000 ha of forest.

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WASTE PAPER RECYCLING: ECONOMIC AND ENVIRONMENTAL IMPACTS

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Abstract

The Optimal Fibre Flow-model, a combined optimization and simulation model, calculates the optimal combination of energy recovery and recycling of waste paper for paper and board production. In addition, the environmental impact is estimated by using an Environment Load Unit-index (ELU-index). The ELU-index assigns an environmental load value to emissions and to the use of nonrenewable resources such as oil and coal.

In the model the value of waste paper depends on the price of fossil fuel and round timber. Assuming unlimited de-inking and energy capacity, the model optimization shows that from a business perspective, paper and board production is profitable with high utilization rates of waste paper, for example 57% for Scandinavia and 84% for the rest of Europe. However, from a societal perspective, a high utilization rate can result in reduced profits, higher prices for paper and board products, or increased emissions of carbon dioxide to the atmosphere.

If the Scandinavian forest industry uses hydroelectric energy in pulp and paper production and the utilization rate of waste paper increases, both oil consumption and the ELU-index increase. However, a political decision that would force the forest industry to decrease its utilization rate and thus favor a 10% increase in energy recovery would result in a marginal loss for the Scandinavian forest industry of about 5.5 USD/ton.

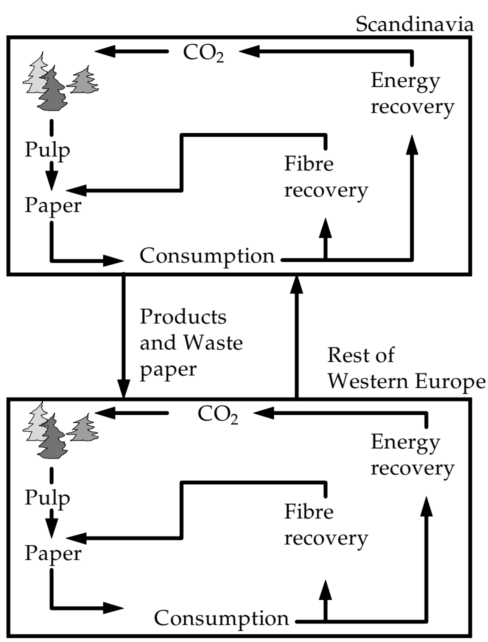
On the other hand, if the electricity is produced from fossil fuel, the ELU-index is initially quite stable but later increases. A minimum is found at a utilization rate of about 25 per cent. The total oil consumption of the European forest industry describes a similar development. Here, a

forced decrease in the utilization rate, along with a 10% increase in energy recovery, would cause a marginal loss for the Scandinavian forest industry with about 6.5 USD/ton.

Introduction

Concern about the environment, demands for economizing in the consumption of resources and an increased interest in reuse and recycling philosophy are strong currents in modern society. The targets for environmental criticism are often the throwaway mentality of consumer society and the large-scale material and energy requirements of the processing industry. The forest industry has thus become a convenient target for the environmental ambitions of consumers and politicians. In countries like Germany, Sweden and the USA this has led to demands for changes in the industrial forest production system. The forest industry of the Nordic countries fears that political decisions made by the European Union or by individual countries will force a fixed utilization rate for waste paper in paper and board producing. There is a risk that such decisions will lead to a suboptimal use of waste paper if the environmental impacts of alternative uses are not considered. Important alternative uses in this regard are recycling for production of paper, energy recovery and landfill. Figure 1 gives a principle outline of linkages of the fibre flow when Western Europe is divided into two regions.

Figure 1. Principle flow of fibres in Western Europe.



The benefits of paper recycling have not been fully analyzed (Grieg-Gran, 1994), through increased recycling is generally assumed to be desirable and necessary. Waste management policy in a number of countries is characterized by a prevailing hierarchy of options in which waste minimisation, reuse and recycling are all considered preferable to energy recovery, which in turn is considered superior to landfills.

Any assessment of recycling should compare the impacts of recycling and their associated costs and benefits with those of alternative options for waste disposal. A key issue is the impact on energy use in manufacturing. Processing waste paper for paper and board manufacture requires energy that is usually derived from fossil fuels. In contrast to the production of virgin fibre-based chemical pulp, waste paper processing does not yield a thermal surplus and thus thermal energy must be supplied to dry the paper web. If, however, the waste paper was recovered for energy purposes the need for fossil fuel would be reduced and this reduction would have a favourable impact on the carbon dioxide balance and the greenhouse effect. Moreover, pulp production based on virgin fibres requires consumption of roundwood and causes emissions of air-polluting compounds.

Approach

Literature Reviewed

Examples of early economic studies of demand for, supply of or trade with waste paper are Grace et al. (1978) and Yohe (1979). They examined international trade and its importance to prices. Price expectations and the effect of price changes have been analyzed by Edwards (1979), Deadman & Turner (1981), and Kinkley & Lahiri (1984). Gill & Lahiri (1980) and Edgren & Moreland (1989) have found low price elasticities for waste paper, a finding which indicates that price subsidies are not to be recommended for stimulating increased use. In a Swedish study of the printing industry, Rehn (1993) shows that the uses of pulp, pulp wood and waste paper are each sensitive to their own price changes so that they will likely substitute for each other.

Lately, systems analysis and extensive modelling approaches have been used for studying the waste paper problem. Colletti & Boungiorno (1980) and the NAPAP model (Ince, 1994; Zhang et al., 1993) concentrate on production and economic aspects of waste paper recycling. Virtanen and Nilsson (1992) incorporate environmental aspects of recycling into their study.

Colletti & Boungiorno (1980) developed a linear programming model of the US paper and board industry. End-use, production and processes for recovery of paper are included in the model. Different demand and supply scenarios are simulated for a ten year period. The model illustrates that waste paper is one possible material source for the paper and board industry but that recycling will only partly solve the landfill problem. Furthermore, the results show that the demand for and the supply of waste paper are dependent on recovery and utilization rates. This conclusion is supported by Turner's & Deadman's (1983) study of the waste paper market in Great Britain. Grace & Turner (1979) point out that technological development influences the change in utilization rates. Using a regionalized partial equilibrium model Trømborg & Solberg (1995) show that the harvest and price of spruce pulpwood in Norway will be lowered significantly with increased utilization rates.

Another example of an extensive modelling approach is the development of the North America Pulp and Paper (NAPAP) Model, the result of a collaboration between the US Forest Service and Forestry Canada (Ince, 1994; Zhang et al., 1993). As in Colletti's & Boungiorno's model, the methodological base is neoclassical economic theory. With linear programming, a solution is found. The model has been used to develop long-range projections of trends in paper recycling, pulpwood markets, and related technological trends in the pulp and paper sector. One conclusion is that the availability of improved technology and the abundance of recycled fibre resources are primary determinants of the recycling rates and of global competitiveness in pulp and paper for North America (Ince et al., 1994). However, environmental effects are not considered. Results from the study are also reported by (Durbak et al., 1990; Ince et al., 1992 and Jacques & Ince, 1992).

Virtanen and Nilsson (1992), however, stress the environmental effects in Western Europe of paper recycling by applying of life cycle analysis (LCA) to fibre use, i.e., impacts of different options are compared over the whole life cycle; in this case from fibre production, pulping and paper making, transport and distribution through recycling and waste disposal. In LCA studies there are frequently disagreements about the definition of cradle and grave (Grieg-Gran, 1994.). Some studies start from the raw material inputs required to produce the product under study; others go further and include the environmental impacts associated with the production of such materials. LCA studies usually make a distinction between the inventory stage - which is identification and quantification of different types of impacts - and assessment, which evaluates the significance of the environmental releases and resource use. LCA studies are normally limited to quantification of environmental impacts. Economic impacts such as changes in raw material cost or increases in collection costs are rarely included.

Virtanen and Nilsson (1992) apply a non-optimizing model which does not include aspects such as fibre age and material composition. One conclusion is that the recovery of waste paper for industrial and energy uses has economic and environmental advantages. Under some conditions the renewable character and the high energy content of paper and wood seem to make energy recovery more attractive than recycling. They recommend a balanced mixture of recycling and energy recovery since recycling minimizes the use of certain resources and emissions, while energy recovery minimizes the overall use of fossil fuels. The appropriate balance may vary from country to country in Western Europe. They stress that more research is needed on the environmental impacts of recycling in relation to how far recycling is taken and how selective it is. Also, the dependency between product quality and utilization rates needs to be studied. In general, more quantitative results are needed instead of qualitative judgements.

A comprehensive review of existing information on the paper cycle from forestry through to recycling, energy recovery, and waste paper disposal has been prepared by The International Institute for Environment and Development (The Sustainable Paper Cycle, 1995). Various flows and linkages of the paper cycle are presented with an emphasis on conventional indicators such as production volume and economic variables. Economic, social and environmental impacts of the paper cycle are examined. It is worth noting that consultant companies have done some interesting analyses. Examples are Virta (1993) and FAO (1994) which give, respectively, valuable data and an analysis of the consequences of increased recycling in four different countries.

Aim and Methodology

In this paper, a modelling approach considers both an economic and an environmental measure of waste paper recycling. Characteristics of the model are:

- A simultaneous treatment of the following sectors:
  - Energy and fibre
  - Environment and economy
  - Quality and waste paper admixtures
- Simple system limits, i.e., an inclusion of most of the fibre production and fibre use in Western Europe, and
- A user-friendly model called the Optimal Fibre Flow Model.

The following questions are answered by the Model:

- What are the business economic costs of different recovery requirements?
- What are the environmental impacts of different recovery requirements?

The dynamics and development of the fibre cycle are analyzed using a combined optimization and simulation model. An engineering approach is taken to describe the production processes. However, both economic and environmental aspects are considered. The Model generates optimal flows of fibres under different assumptions. Consideration of the affect of all relevant processes and transports on the environment are included in the Model; for example, the carbon dioxide balance is calculated in the system. Thus, the Model not only includes calculations of the industry-related fibre cycles but also the role of forestry and forest products in the climatologically important circulation of carbon dioxide. The environmental effects of the different activities in the total system are also added using the same methodology as used in some life cycle analyses, where each individual emission and each use of nonrenewable resources, such as oil and coal, is given an environmental load index value (ELU-index) taken from a system for Environmental Priority Strategies in Product Design, the so-called EPS-system (Steen & Ryding, 1994). The system is based on the willingness of people to pay for avoiding the consequences of different emissions. We register all production processes and emissions instead of as in the established methodology of life cycle analysis concentrating on just paper and board production. An additional reason for including all production processes and emissions is to demonstrate that the forest industry is not the large and dangerous polluter it is often perceived to be.

In the following text we provide an overview of the energy use and energy production of the forest industry. Mills based solely on virgin fibres are compared with mills based on waste paper. After this, the Optimal Fibre Flow-model is presented. An overview of its structure is given, followed by a more mathematically oriented presentation. In this section the ELU-index is also presented. A short description is given of the data used. The presentation of the results starts with the optimal waste paper use when a business economic criteria is applied. Different requirements are then applied to the Scandinavian utilization rate and the consequences for the environment are calculated. The article ends with some concluding remarks about the utilization of waste paper.

Use and production of energy in the forest industry

When analyzing the two alternatives for circulation, recycling for production of paper and energy recovery it is necessary to understand the energy use and energy production of the forest industry and their impact on the environment.

Figure 2 shows a principle outline of energy use and energy production for pulp mills. Chemical pulp processes yield a thermal surplus from wood and high

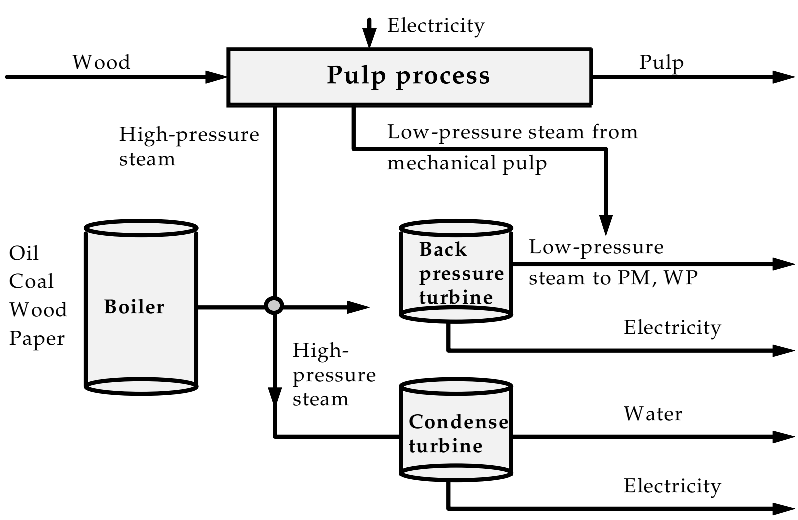


Figure 2. A principle outline of energy use and energy production in pulp mills.

pressure steam, a part of which can be transformed into electricity with a back pressure turbine. Most of the remaining low pressure steam is used for drying the paper web. Thermo-mechanical pulp processes that are based on electricity produce low pressure steam that can be used for the same purpose in the paper mill. Using waste paper to produce paper and board requires that this energy is replaced, usually by energy based on fossil fuels. On the other hand, pulp production based on virgin fibres causes emissions of certain compounds. Let us clarify the energy use and energy production of the paper and board industry by two examples.

The total use of electric energy when office paper is produced from virgin pulp is about 5 GJ/ton (Figure 3). Excess energy from the pulp mill (about 7 GJ/ton pulp) can be used for drying the paper. If waste paper is used for energy recovery, about 11.5 GJ of heat per ton will be produced. On the other hand, if office paper is produced from recycled pulp, thermal energy must be added to the de-inking mill (2 GJ/ton) and to the paper mill (about 5.95 GJ/ton). Thus, instead of getting 11.5 GJ of thermal energy per ton as in the first case, 7.95 GJ of heat per ton must be added to the 4.38 GJ of electric energy. This increases the need for fossil fuel quite substantially, even if minor amounts of electric energy can be saved.

If newsprint is produced from thermo-mechanical pulp (TMP), the excess energy from the pulp mill (about 6 GJ/ton pulp) can be used for drying the paper (Figure 4). However, a lot of electric energy is used; 10.5 GJ/ton must be added. This corresponds to approximately 20 GJ of heat energy per ton if a condense turbine power plant is used. If newspaper after consumption is used for energy recovery 11.5 GJ of heat per ton will be produced. On the other hand, if newsprint is produced from de-inked pulp, thermal energy must be added to the de-inking process (2 GJ/ton) and to the paper mill (5.1 GJ/ton). Thus, instead of getting 6 GJ of thermal energy as in the first case, 7.1 GJ of heat per ton must be added. However, the use of electric energy is only 5.2 GJ/ton which is 5.3 GJ/ton less than when TMP is used. Thus, in total the energy saving for the whole system when TMP is used is about 7 GJ of heat per ton. If waste paper were burnt there would be a reduced need for fossil fuel, which would have a favourable effect on the carbon dioxide balance and the greenhouse effect.

Model

Western Europe is divided into two regions, Scandinavia (Finland, Norway and Sweden) and Continental Western Europe and the U.K. (compare Figure 1). Each region has production resources and a market for paper products and energy. The products produced are delivered either to the domestic market or to the export market. After end-use, paper is recycled for production of paper and board and/or recovered for energy use. If recycled, the waste paper is recovered, sorted, baled and transported to paper mills in one of the regions for production of recycled pulp

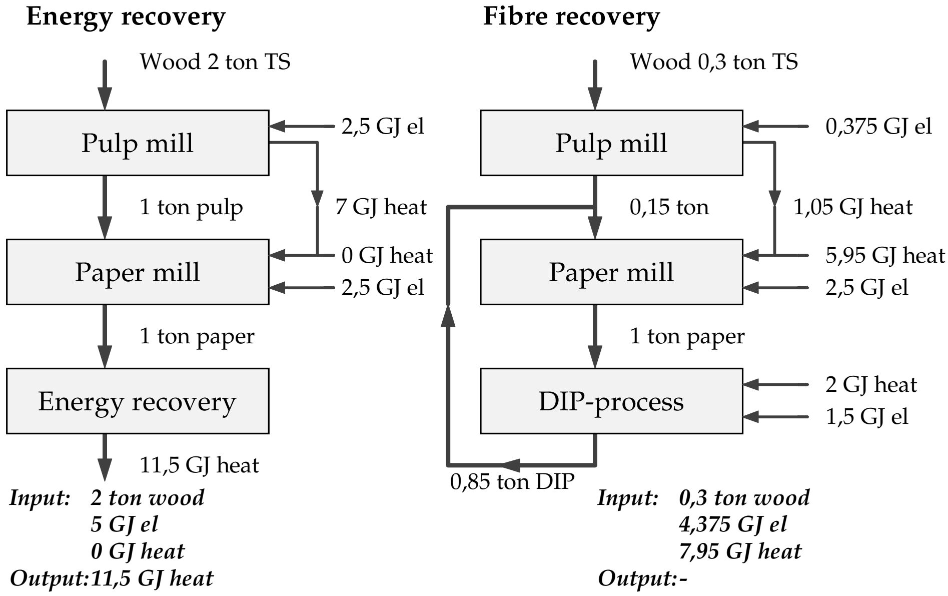


Figure 3. Use and production of energy in office paper production.

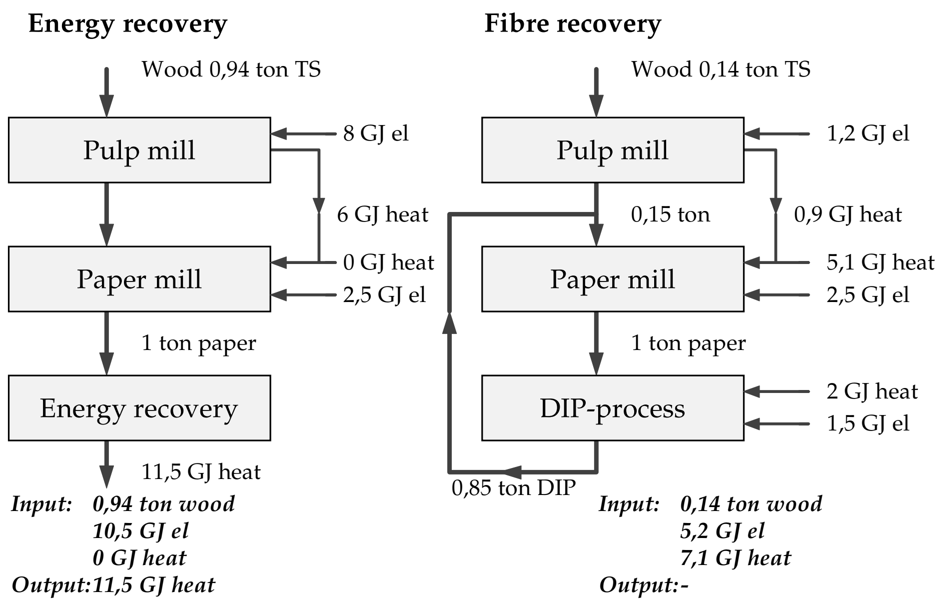


Figure 4. Use and production of energy in newsprint production.

(Figure 5). If recovered for energy use, the waste paper is assumed to follow the normal waste-handling system. It then replaces oil or coal. Eventually, the collected paper is exported to Scandinavia or the rest of Western Europe. The production value of waste paper depends on the price of fossil fuel and round timber. The higher the price of oil, the more waste paper is recovered for energy purposes. Waste paper which is not reused has no value in the Model. Thus, in the Model all waste paper is recovered. It is assumed that enough capacity exists for de-inking and energy production.

Twelve different paper qualities are produced in the Model: Newsprint, SC paper, LWC, office paper (wood-free), coated paper (wood-free), tissue, white lined chipboard, ”return fibre chipboard”, wrapping paper, white liner, kraft-liner and fluting. Recipes specifying the need for fibres, filler and energy are given for each product. The Model chooses between virgin fibres and recycled fibres in keeping with the quality expected of the products.

Five different flush pulps and market pulps are included. Dried pulp in sheets is delivered from Scandinavian producers to nonintegrated paper mills in other parts of Western Europe. The need for pulp wood (short and long fibres) and energy is specified for each of the pulp qualities. Surplus energy from pulp processing is used in the paper production. Electricity can be produced from back pressure power or in condensation power stations that burn coal, oil, wood or waste paper.

Costs connected to the different processes are considered. The age distribution of the fibres in each product is calculated (Byström & Lönnstedt, 1995; also compare Göttsching, 1993). The model includes the yields in different processes, and these can be made age-dependent. Furthermore, the energy needs for production of chemicals are included. Different types of emissions to the atmosphere and water, except those from chemical plants, are calculated and later converted into comparative environmental indexes. Below, we describe the different subsystems that make up the Model.

Forestry

This part of the Model describes how the forest absorbs carbon dioxide. Timber harvest and transport cause energy consumption and costs. Energy used in producing fertilizers is also considered.

Pulp mill

This module describes the production of pulp using wood as the raw material. Apart from wood, use is made of electricity, thermal energy and chemicals. Excess energy in the pulp mill can be used in the paper mill. Electricity can be produced by back pressure steam turbines or by condensing turbines.

Deinking mill

Waste paper pulp is produced from recovered paper. The Model calculates the consequences of poor quality waste paper material. In other respects, the calculations are the same as for the pulp mill.

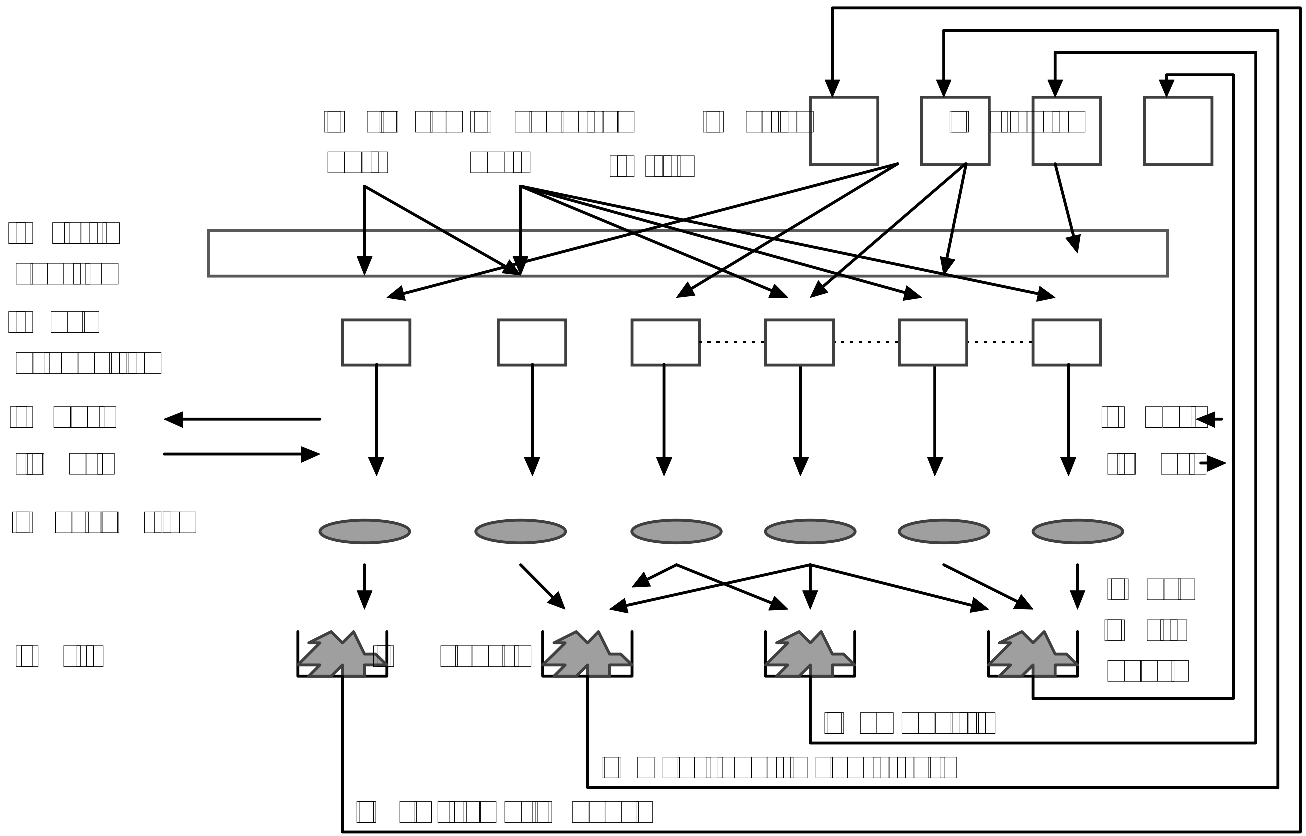


Figure 5. Illustration of the flows in the model.

The yield in the process that produces recycled pulp and the energy value in waste paper are calculated on the basis of the fibre composition of each individual product. In addition, the effect of filler is considered. The efficiency in the recycled pulp mill and the thermal energy recovered from burning paper are dependent on the composition of the paper.

Paper mill

This part of the Model describes how paper is produced from virgin pulp and waste paper pulp. In addition, use is made of different types of energy and fillers. Emissions to the atmosphere and to the water are registered.

The paper products can be produced with different amounts of recovered paper from different products. Restrictions in the Model prohibit, however, incorrect combinations. Wood containing paper is not used, for example, when making wood-free qualities.

Collection and transport

In the Model, collection of waste paper requires energy in the form of diesel fuel and other resources represented by variable costs. Standard emissions to the environment are considered. The need for resources varies depending on the product and the region. The resources needed (energy and money) to collect paper are progressive. For example, depending on quality, the resources needed to collect the last 30% of the consumption are 3 to 6 times higher then those needed to collect the first 30%. It is assumed that sufficient industrial capacity exists to recover waste paper as fibres or as energy.

Energy consumption

All processes, including transport, require energy. All energy in the Model is generated in an energy plant where emissions to the environment are also calculated. Energy can be purchased on the market. Some forms of energy cannot be substituted, e.g., all transports are based on diesel fuel. Electricity and heat, on the other hand, can be generated both by fossil fuel (oil or coal) and by combustion of fibre products (including wood). In Scandinavia, electricity can be produced from water and fossil fuels, whereas the rest of Western Europe must rely on electricity generated by fossil fuels. Naturally, emissions are affected.

Mathematical expressions

Incorporating considerations of demand (demand and prices for the different products are given), maximum existing capacity, production costs, transport costs and availability of raw material, the Model maximizes the profit, or using an economic terminology the producer surplus, by determining the product flows between different regions (export, import) and the waste paper distribution between recycling for production and energy recovery. Finding a solution is somewhat tricky since many processing parameters depend on the composition of the waste paper.

The composition, in turn, depends on the product flows and the distribution of the waste paper in different fields of use.

The linear programming problem is generated from a specially designed system, called GHOST, that includes functions for a simple generation of parts of the LP matrixes describing individual pulp and paper processes. In principle, the submatrixes describing the processes of each mill are generated first. The different processes are linked to each other with references in plain language, for example a market product from one process can be raw material for another process. As hydroelectric energy and energy produced from fossil fuels are viewed at as products, they are generated internally by the Model. The most important relationships are described by equations (1) - (4).

$$R_{pi} = \Sigma C_{ijk} P_{pjk} \quad (1)$$

$$P_{p} = \Sigma P_{pjk} \quad (2)$$

where R_{pi} is raw material *i* used in process *p*, C_{ijk} is the recipe coefficient for raw material *i*, market product *j* and production product *k*, and P_{pjk} is product *j* from process *p* and product *k*. Note that for each market product, *j*, a number of different production products exist, designated by *k*, representing different ways to produce the same market product using different recipes, for example admixture of waste paper.

$$O_{p} = \Sigma R_{pi} Q_{i} \quad (3)$$

where O_p is a part of the goal function and Q_i is the price of bought raw material.

$$C_p \geq P_p \quad (4)$$

where C_p is maximum capacity for market product *j* from process *p*.

Relationship (5) shows that demand for a specified product can be supplied by all producers. Recycled raw materials (6) used for energy or production purposes can at most be collected up to the consumed volume. In the model,

$$D_{mj} = \Sigma P'_{mpj} \quad (5)$$

$$D_{mj} \geq \Sigma W_{mpj} \quad (6)$$

where D_{mj} is the demand for product *j* from market *m*, P'_{mpj} represents the shipments of product *j* from process *p* to market *m*, and W_{mpj} is the recycled flow of product *j* from market *m* to process *p*.

$$O_m = \Sigma T_{pj} P'_{pjk} + T'_{pj} W'_{mpj} \qquad (7)$$

where O_m is transportation costs for domestic and imported products for market *m*. The collection of raw materials is quite complex as the Model distinguishes different collection levels that affect the costs. However, in equation (7) collection is represented by one single coefficient, T. Transports affect the energy balance for each mill, i.e., indicate consumption of diesel oil and emissions. In the Model all emissions are viewed as flows of raw materials from the production processes.

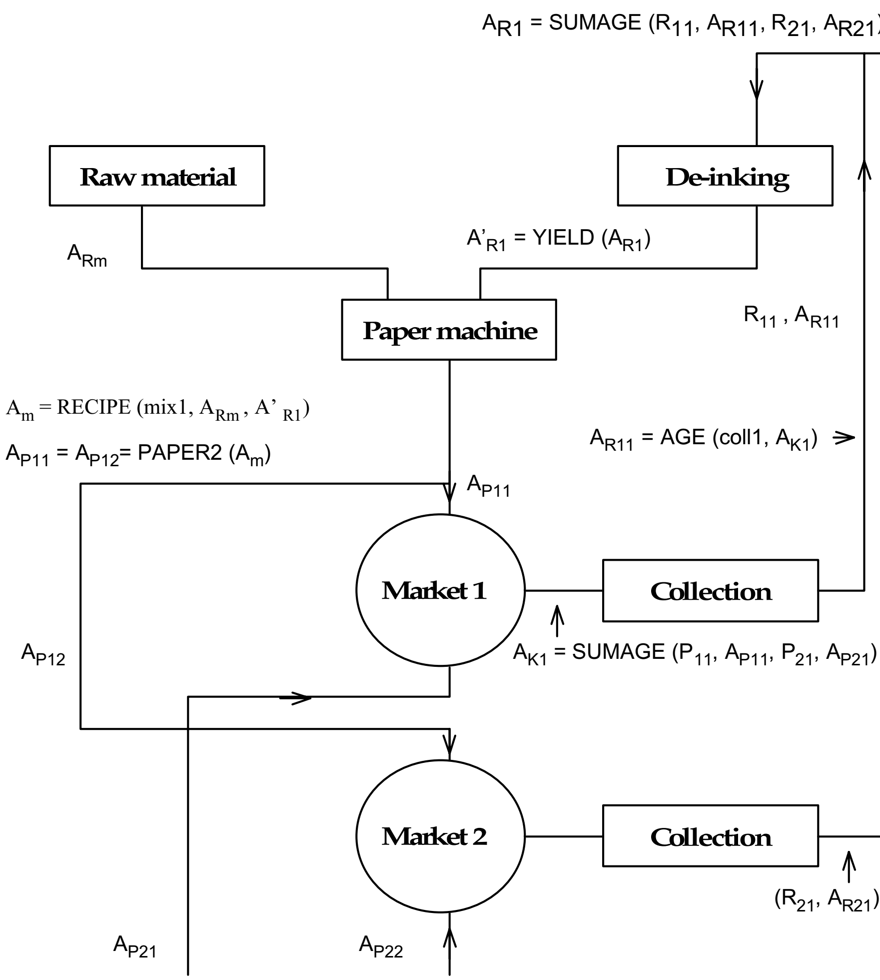


Figure 6. A principle outline of the calculation procedure.

The model follows this procedure for finding the optimal solution:

1. Assumptions are made about the processing factors, for example, the yield when producing paper from waste paper.
2. Based on these constants, an economic optimization is made that gives all relevant flows of material.
3. Knowing the flows of the different products, the age structure of the fibres and the distribution of the material are calculated.
4. Knowing the age and material distributions, an exact calculation of the processing factors can be made.
5. The newly calculated factors are compared with the previous ones. If differences exist a new set of processing factors is calculated, for example, as an average of the two previous sets. Usually it takes just a few runs to find a stable solution.

Unlike other algorithms, the Model starts by calculating the processing factors based on assumed age and material distributions. In the second step an optimization is performed. Alternating between simulation and optimization a stable solution is quickly found.

The procedure for calculating Step 3, i.e., the age structure and material composition of fibres, is described by Figure 6. In addition, the figure shows the flows of paper and board products from region 1 to markets 1 and 2, and the flows of waste paper from these markets to the producers in region 1. The flow of products from producers in region 1 to consumers in region 1 is denoted as P_{11}, a vector with N different products. Correspondingly, the import of paper and board products from region 2 to consumers in region 1 is denoted as P_{21}. The flow of waste paper from consumers in region 1 to producers in region 1 is denoted as $R_{11,}$ a vector with M different waste paper grades. Correspondingly, the import of waste paper grades from region 2 to producers in region 1 is denoted as R_{21}. Correspondingly, P_{22}, P_{12}, R_{22} and R_{12} are defined.

Starting with the two left-hand flows in Figure 6 we describe the principle outline of the calculation procedure. A_{R11} and A_{R21} define the conditions of the fibres in the two respective flows. The data are organized as a cube (Figure 7). (It is not necessary for the number of elements in each dimension to be the same). This method of organizing the data is used throughout the Model.

Given a certain waste paper grade, the resulting matrix, a level of the cube, describes different age classes and different material compositions (type of fibres and fillers). For this type of problem, the number of age classes are often restricted to between 10 and 20. The share of fibres belonging to the higher age classes is exceedingly small. In the calculations, these shares are added to the highest age class.

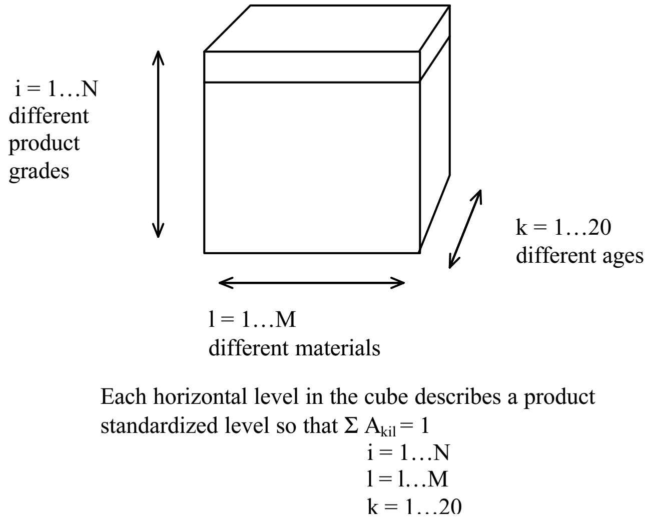


Figure 7. Cube describing the flow of products.

Prior to the de-inking process the flows of waste paper from the domestic and foreign markets are mixed. The volumes are used as weights. The conditions of the fibres in the mixed flow is described by a new cube.

$$A_{R1} = SUMAGE\ (R_{11}, A_{R11}, R_{21}, A_{R21})$$

As a result of the de-inking process, the proportions of chemical and mechanical fibres change. Filler and coating materials partly disappear. The resulting conditions of the fibres after de-inking is described by a new cube:

$$A'_{R1} = YIELD\ (A_{R1})$$

The virgin fibres from the pulping process, i.e. fibres with no circulation, and other raw materials such as fillers are described by the cube A_{Rm}. Based on the recipes used for different products, virgin and older fibres are mixed. The recipe used for each product is described by mix1. The conditions of the fibres in the mixed flow are described by a new cube:

$$A_m = RECIPE\ (mix1, A_{Rm}, A'_{R1})$$

When the fibres pass through the paper machine, mechanical damages occur. Once again the condition of the fibres is changed. The result is described by the following cube:

$$A_{P11} = A_{P12} = PAPER\ (A_m)$$

A_{P11} describes the condition of those fibres in paper and board products shipped to the domestic market and A_{P12} the condition of fibres exported to the other region. It should be noted that market 1 can import paper and board products from region 2. The conditions of those fibres are described by the cube A_{P21}.

After end-use, the paper and board products are recovered. Using the volumes of paper and board products shipped from region 1 and imported from region 2, a weighting is done for calculating the new cube.

$$A_{k1} = SUMAGE\ (P_{11}, A_{P11}, P_{21}, A_{P21})$$

The recovered paper is sorted into different grades. The sorting descriptions are given by coll1. The conditions for the fibres in the different wastepaper grades are described by the following cube:

$$A_{R11} = AGE\ (coll1, A_{R11})$$

We are back to the flows where the description started. The flows for region 2 are defined in the same way.

The steps in the algorithm for finding the age and material distributions (step 3 in the solution algorithm described above) are as follows:

1. Guess the initial values of the A_R-cubes, denoted as $A^{(1)}_R$.
2. Calculate $A^{(1)}_P = f(A^{(1)}_R)$
3. Calculate $A^{(2)}_R = f(A^{(1)}_P)$
4. Compare $A^{(2)}_R$ with $A^{(1)}_R$. If they differ, put $A^{(1)}_R = A^{(2)}_R$ and repeat the calculation, otherwise stop. Experience shows that 30 iterations are enough to find a stable solution. The calculation takes just a few seconds on a powerful PC.

Environmental Load Unit -index

To calculate the environmental impact of the pulp and paper production, the use of nonrenewable resources and the effects of emissions are added together. In the Model this is done by using an Environment Load Unit-index (ELU-index) (Steen & Ryding, 1994). For example, the ″value″ of the use of 1 kilogram of fresh water in areas with a water deficiency is 0.003 ELU. As can be seen in Table 1, the ″punishment″ for destroying 1 m^3 of oil is 360 ELU. The ELU-index for nonrenewable resources reflects the market value of the resources, i.e., the demand and supply conditions. This explains why oil has a higher value than, for example, coal. Depending on use and emissions a value may be added. If oil is used as fuel, emissions from incineration are added. The Model only takes into account the ELU-index for important emissions and for the use of nonrenewable raw materials. Effects on biodiversity caused by forest management and similar environmental impacts have not been assigned an ELU-index in this Model.

Table 1. ELU-index used in the Model.

Fossil oil	ELU/m^3	360
Diesel oil	ELU/m^3	336
Fossil coal	ELU/ton	100
CO_2	ELU/ton	88.9
CO	ELU/kilo	0.269
NO_x	ELU/kilo	0.217
S	ELU/kilo	0.1899
COD	ELU/kilo	0.0016

Data

The input data for the Model are prices, efficiencies and costs of production and transport. The fibre furnish and energy needs for each paper quality are specified. For each type of pulp, the need for wood and energy and the emissions to the environment from the production process are specified. Sources for the data are the Swedish Pulp and Paper Research Institute (Haglind et al. 1994) but also databases at the MoDo Company. Data from Germany is assumed to reflect the situation in the whole of Western Europe. Vass and Haglind (1995) have made a Swedish literature review of the environmental consequences of utilizing waste paper. The review contains valuable data about sludge, chemical use, transports, use of energy and emissions to air and water. The data for Sweden are reliable while the quality of data for the rest of Western Europe can be improved.

An extensive collection of data on the production of and trade in Western European forest products for 1990 has been carried out (Byström & Lönnstedt, 1995). This was the year for which the most up-to-date data for the countries studied could be found.

Results

Economic use of waste paper

Using a production value of waste paper based on the prices of fossil fuels and round timber at the beginning of 1995, the most economical utilization rate for the Scandinavian forest industry is 57 per cent and 84 per cent for the forest industry in the rest of Western Europe. Thus, the economic optimization shows that from the perspective of business economics a high utilization rate is profitable. If hydroelectric power is used in pulp and paper production and the Scandinavian forest industry is forced to decrease the utilization rate by 10 per cent, the marginal loss is about 5.5 USD/ton. On the other hand if the electricity used is produced from fossil fuels, the loss is about 6.5 USD/ton. While mandatory utilization rates are set, the Model is free to optimally determine the admixture of waste paper for different products.

If the price of waste paper is defined by the prices of fossil fuels and round timber the answer to one of our initial questions of view is obviously that a high utilization rate is to be preferred from a business point. However, from an environmental perspective, the answer is quite different.

Environmental impact

The Model, accounting for all process restrictions, always maximizes the marginal revenue for the forest industry. It can, however, be forced to take additional restrictions into account. In the following examples the Model is forced to save forests in Scandinavia by recycling fibres. Given the restrictions, the Model optimizes the use of waste paper for energy recovery and recycling.

Figure 8 shows the use of fossil oil in the whole system when the utilization of recycled fibres in Scandinavian paper and board production changes. If electricity is produced from fossil fuels, the curve, with increasing utilization rates, first decreases and later increases. It has its minimum at a utilization rate of about 25%. If the paper production is based on hydroelectric energy, oil consumption increases continuously.

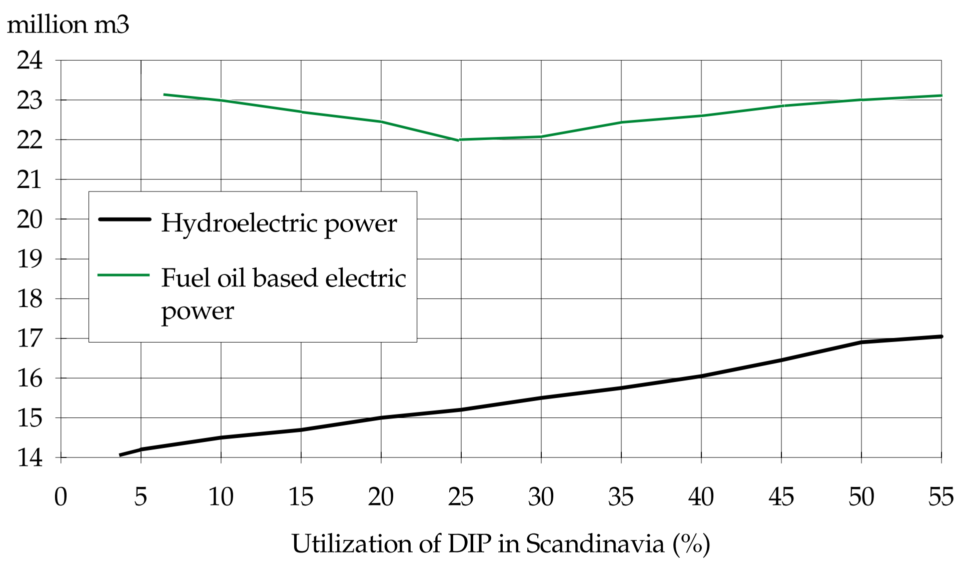


Figure 8. ***Consequences for oil consumption of a forced increase of Scandinavian utilization rates of de-inked paper (DIP).***

As oil consumption only tells part of the story, Figure 9 shows the total environmental impact measured as change in the ELU-index per ton of paper and board produced in Scandinavia. Furthermore Figure 9 illustrates the difference in load depending on whether the electricity in Scandinavia is hydroelectric or based on fossil fuels. During the first part of the 1990s, 47.5 per cent of Swedish electricity was produced at hydroelectric power stations.

As the de-inked paper utilization rate increases from 5% to 55%, the increase in load is about 100-150 ELU/ton paper. The disadvantage of recycling is greater if the electricity is hydroelectric.

However, if electricity is produced from fossil fuels the ELU-index, with increasing utilization rates, decreases up to a utilization rate of about 25 per cent. After this, irrespective of the energy base, increased utilization of recycled paper is harmful for the environment.

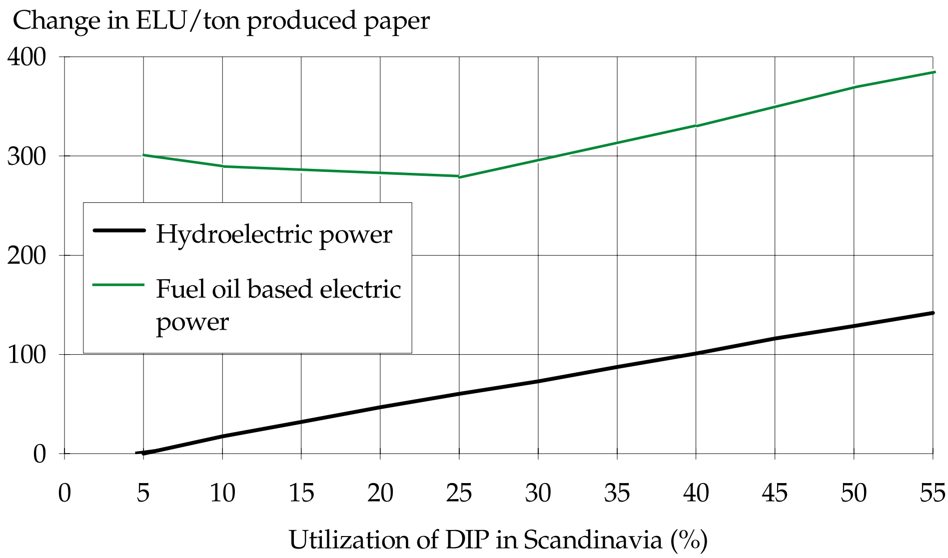


Figure 9. ***Consequences for the environment (measured by the ELU-index) of a forced increase of Scandinavian utilization rates of de-inked paper (DIP).***

In another example, use of waste paper is forced when producing newsprint and office paper. As above, a comparison is made between hydroelectric power and fossil electricity. The results are summarized in Table 2.

Table 2. ***Increase in environmental impact in ELU/ton product for every 10% increase in recycled fibres.***

In the case of newsprint, the environmental impact depends mostly on what type of

	Hydroelectric power		Fossil electricity	
	Newsprint	Office paper	Newsprint	Office paper
Non-renewable resources	14	10	-10	10
Emissions	18	13	+2	10
Total	32	23	-8	20

electric power is used. If electricity produced by hydroelectric power is used, the increased use of recycled fibres has an adverse effect on the environment. The index increases by 32 ELU/ton newsprint for every 10 per cent increase in recycled fibres in the product. The explanation for this increase is that when paper is recycled as fibres the thermo-mechanical pulping process no longer converts electricity into heat energy which is needed in the papermaking process (compare with above). This energy loss is compensated for by fossil (oil) energy which is the cheapest available alternative. In addition to being a nonrenewable resource, the burning of oil for energy produces emissions, of which carbon dioxide is the most important.

If, on the other hand, the electricity for newsprint production is generated from fossil fuels, an increased utilization rate has a favourable environmental impact. The explanation is that in this case the electricity, used for producing TMP, is produced from fossil fuel in condensing power plants with low efficiency (40%). If the electricity is not needed, as is the case when waste paper is used, it is more efficient to produce this heat directly from fossil fuel. Differences in the type of transport of wood and waste paper contribute only slightly to the differences in the ELU-index. However, the index does indicate a small increase in environmental impact, mainly due to larger emissions.

In Table 2, figures describing the environmental impact caused by changing the utilization rate of recycled pulp in woodfree office paper are also included. The chemical pulp process converts about half of the wood used into pulp. The remainder of the wood raw material can be burned to create excess thermal energy that is normally used in the papermaking process. If recycled fibres are used, the energy required for recycling plus the energy lost when the waste paper is not burned, must be derived from other sources, such as oil or coal. Even if clean electricity is used, increased fibre recycling has a negative impact on the environment.

Conclusions

In the introduction to this paper we wrote that waste management policy in a number of countries is characterized by a hierarchy of options in which waste minimization, reuse and recycling are all considered preferable to energy recovery which in turn is considered superior to landfills. The issues are highly complex and the science for assessing them, life cycle analysis (LCA), is still in its infancy. Little analysis of the benefits of paper recycling has been made. Using the principles of LCA and a systems analysis approach simultaneously, we have studied the different alternatives.

The ELU-index gives no evidence that increased recycling is an environmentally-friendly policy (compare Kärnä et al. 1993). The result supports energy recovery from waste paper as a substitute for fossil fuels. This substitute will diminish the greenhouse effect. However, one consequence of replacing fossil fuels with energy recovery from waste paper may be a reduction in actual or potential profit levels for the forest industry.

It is of vital interest for humankind to decrease carbon dioxide in the atmosphere to avoid global warming. Maximum energy recovery of waste paper would only marginally influence the carbon dioxide balance of Western Europe (a few percents of the total fossil fuel use in Western Europe). Increased production of pulp based on wood, or use of waste paper as fuel, are both examples of a development that leads to replacement of fossil fuels and a consequent decrease in the release of anthropogenic carbon dioxide. Increasing the land area holding growing forests, which absorb carbon dioxide, is another way.

A major problem in many countries, and a driving force behind legislation, is the large volumes of paper and paper products in household waste, and the scarcity of room for landfills. These factors make for a strong argument for waste paper collection, especially in the densely populated countries of Western Europe. The question of whether the collected paper is recycled as raw material for paper or for energy production is secondary to the importance of using landfills efficiently.

The economic and political aspects of this question, however, are critical. Price relations between different forms of energy rule market demand, and energy prices are influenced by political decisions. The linkage between the different decision levels are complex. One important goal for the industry is to maximize profits. National governments determine national environmental policies, which affect the decisions taken by the industry. On the third international level, for example, the European Union, the policies of national governments need to be coordinated and formulated as an international environmental policy capable of dealing with the intensive trade in forest industrial products and the fact that emissions move over national borders. The conditions under which the model operates can be varied to account for, for example, for legislated requirements for recovery or admixture of waste paper, and the costs involved for virgin fibres, old fibres and fossil fuels.

The results of the project provide important data for decision-making among politicians, business management and environmental groups. Quantitative estimates are presented that can be used instead of qualitative judgements and general thinking. Hopefully the results will influence the debate in Europe regarding the use of waste paper.

For follow-up research on this issue we recommend that consideration be given to dynamic effects as changes in production capacities and product prices. As such, several interesting research topics exist:

- Include the markets, demand for and supply of forest industrial products, round timber and waste paper. This will allow a calculation of consumer and producer surplus. It is important to include social impacts such as employment rates.

- Analyze the consequences for the structure of the Western European forest sector of increased waste paper recovery and an increased utilization rate. Where will the new paper and board capacity be located? How will the quality of waste paper be affected? What effects will an increased use of waste paper have on the fibre flow and qualities?
- Given different assumptions about consumption, technological development and institutional changes (new laws), analyze when a balance between use of new and old fibres will be achieved.
- Change the boundaries of the system to include bioenergy as an alternative for fossil fuels.

For future studies of this kind, access to reliable data may prove a serious problem. Finland and Sweden have accessible data bases. The rest of Western Europe, however, has another tradition. Much would be gained if shared accessible data bases were developed in more countries or by a European organization. It is important that data acquisition, transformation and storage in data banks are made compatible. In this way, decisions of great consequence to our environment could be made on a more knowledgeable basis.

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PAPER RECYCLING IN DENMARK - POLICY ISSUES AND IMPACTS

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Abstract

The focus on environmental impacts from the use or non-use of secondary wood fibre results probably from national and sectorial interests in the economic consequences of recycling. With an environmental policy controlling the production and the disposal of solid waste a preferable recycling policy seems to be with no intervention and determined by the market conditions. Denmark is a distinctive national case of paper recycling that sheds light on the importance of the market mechanism, the trade deficit of paper and paperboard, and the lack of a pulp and paper industry. Denmark's paper and paperboard imports can be turned into economic gains by increasing recycling. The potential for a regulation of the recovery and utilization of secondary fibre is restricted when the environmental impacts of imported commodities are outside the spatial jurisdiction of an environmental policy. The objectives put forward for recovery targets are not comparable because the international trade dilutes the secondary fibre content in the final consumption, and some national figures includes *mill-broke* from the paper processing. It is the *post-consumer* fibre content in the final consumption that is the comparable measure. The economics of energy recovery versus fibre recycling shows the best feasible use of secondary fibre. The level of economic energy recovery depends on the cost saving from the substituted virgin fibre. It is shown in an energy budget model that even though energy recovery may seem to be preferable, the energy balance of recycling is comparable only when different alternatives have the same boundary for the life-cycle.

Introduction

Recycling of paper in Denmark is a case revealing the significance of the business economic allocations for the recovery and utilization of secondary wood fibre, but also of the structure of the pulp and paper industry and the foreign trade pattern. The pattern of the recovery and use of secondary wood fibre in Denmark reveals characteristic topics, e.g. the influence on the foreign trade balance, the environmental impacts being found in other countries, and the national significance of paper production and consumption in a comparative analysis. A considerable disorientation exists on the methodology for analyzing the economics and environmental impacts of recycling schemes. Commonly environmental impacts of recycling are assessed partially and in isolation while the economic impacts are precluded. This adds to the perplexity on the interpretation and comparison of the results from various studies. An analysis is furthermore baffled because the objective is seldom an optimal social outcome but enhancement of particular interests, e.g. an environmental movement, the pulp and paper industry, or the forest sector. An emphasis on environmental impacts provides no transparent answer and is biased by the underlying economic interests, e.g. appealing to consumer preferences and an enhancement of sector interests.

There are arguments favouring both the environmental benefits of utilizing virgin fibre and secondary fibre, and the possibility of energy recycling from recovered paper further complicates the issue. Two issues on paper recycling have been intensively debated in Denmark: (i) energy recovery or material recycling of secondary wood fibre, and (ii) the impacts of paper recycling on forests. A Danish action plan for recovery of secondary materials has been the basis for a governmental analysis of the economic and environmental impacts of paper recycling in comparison with energy recovery. The main results from the analysis are that an increased recycling is more profitable than energy recovery due to the trade impacts while nothing decisive can be concluded on the environmental impacts. The energy recovery option is theoretically examined by: (i) a crude economic model, and (ii) an analysis of the energy balance. It is no coincidence that these issues have been raised in particular by the forest sector interests losing a relative market share, while the significance of a social welfare gain is concealed.

Finally, a discussion on the design of policy instruments is included. The information gathering on the environmental and economic impacts should be a departure for recycling policy and the use of secondary fibre, e.g. at the national level, in the single firm or even for the choice by individual consumers. The disclosure of the expected impacts may justify an intervention when the market equilibrium has another allocation ignoring external costs. A market intervention may, however, also cause failures, e.g. a distortion of secondary markets making them unable to clear. It therefore also must be examined whether a governmental intervention with regulation of recycling policies is feasible and desirable.

1. *The recovery and utilization of secondary fibre in Denmark*

The national levels of paper recycling can be described by the *recovery rate* of secondary wood fibre[1] and the *utilization* rate[2]. The difference between the recovery and utilization of secondary fibre is levelled through a foreign trade in secondary wood fibre and changes in stocks. The recovery and utilization rates differ when the paper and paperboard consumption and production is balanced through foreign trade. The utilization rate is not a realistic measure of the national recycling effort, because a few nations in Europe are net-exporters due to the existence of forest resources but more nations are substantial net-importers. A measure with a stronger relevance to governmental regulation is the content of secondary fibre in the domestic final paper consumption. Since the secondary fibre content in the imported paper products is unknown, the final consumption of secondary fibre in Denmark cannot be assessed.

Denmark has a substantial deficit in the supply of paper and paperboard (Table 1). The relatively small volume of the domestic paper production compared with the consumption results in a gap between the recovery and utilization rates though the volumes of secondary fibre does not differ substantially. The domestic production of paper and paperboard does not meet the domestic demand. It should be noted that within the paper industry wood fibres are recovered in the production process (*mill-broke*). Although these secondary fibres have not been utilized in the final consumption they can be accounted for in the recovery and utilization rates. A large domestic paper industry thus enables a larger recovery and utilization rate with the inclusion of *mill-broke*, and the national figures are not comparable.

Table 1. Paper and paperboard in Denmark (1992).[3]

	1,000 m.t.
Consumption of paper products	1,193
Recovery of secondary fibre (recovery rate: 36 %) (*)	424
Production of paper products	380
Consumption of secondary fibre in domestic production (utilization rate: 83 %)	315

Note:(*) The amount includes only the amount purchased by the traders in secondary wood fibre.
Source: Rendan (1993)

[1] *Recovery rate:* The share of secondary wood fibre recovered from the domestic wood fibre consumption (*post-consumer*) or paper production (*mill-broke*). It does not reveal the share of secondary fibre in the paper consumption.

[2] *Utilization rate:* The utilization of secondary wood fibre in relation to the domestic paper production.

[3] The latest available figures on the recovery of recycled fibre are from 1992. The Danish figures on the recovery of secondary fibre can be assessed according to different procedures and information sources (Rendan 1993). A larger figure commonly presented for the 1992 recovery is 467,000 m.t. corresponding to a recovery rate of 39 %.

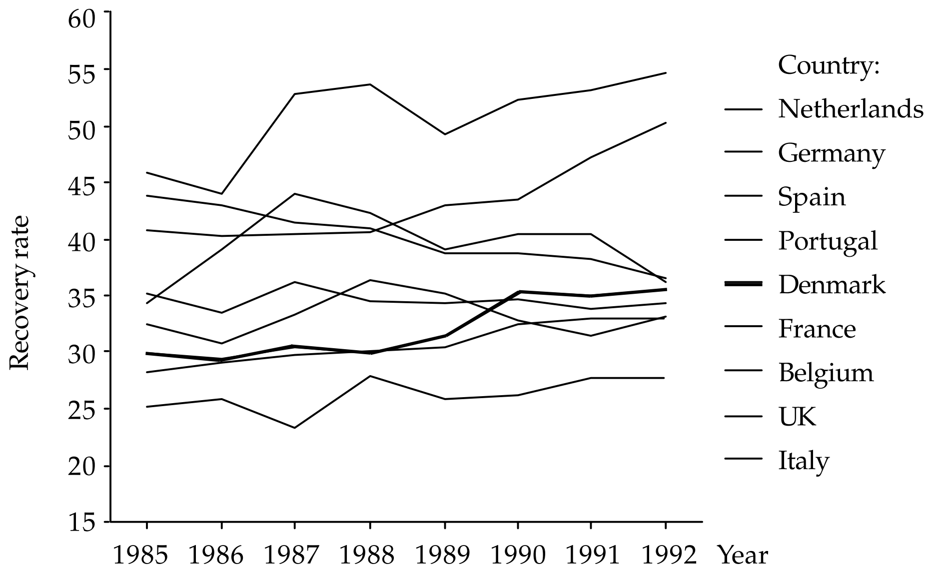

Figure 1. ***The recovery rates of secondary wood fibre in Denmark and other European countries (1985-1992) (compiled form various FAO sources).***

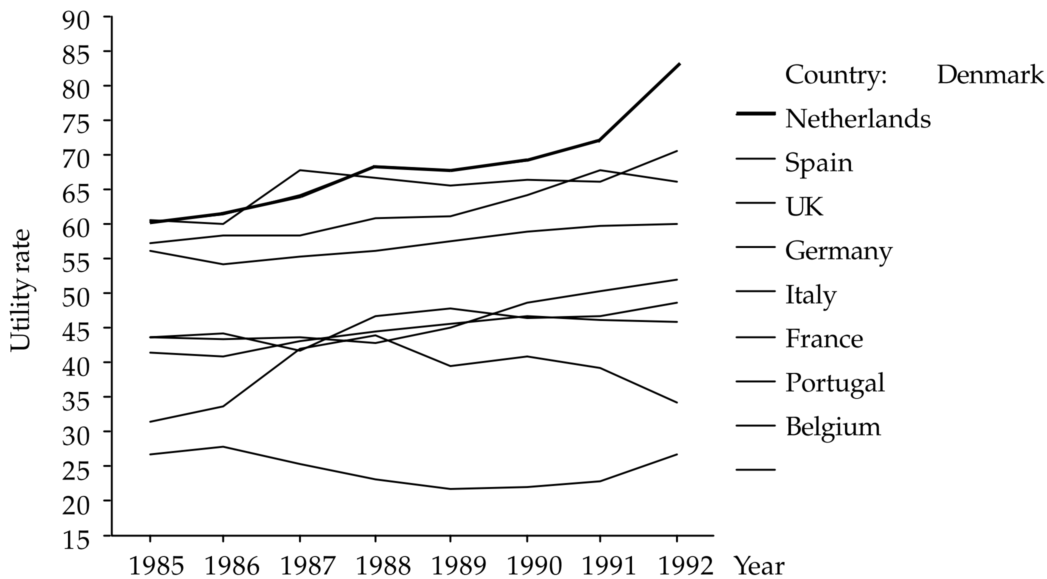

Figure 2. ***The utilization rates of secondary wood fibre in Denmark and other European countries (1985-1992) (compiled form various FAO sources).***

In a international setting, the recycling of wood fibre in Denmark has poor records when the comparison is based on the *recovery rate* (Figure 1) while excellent records are presented by the *utilization rate* (Figure 2). None of the comparisons provide an useful measure of the level of recycling because the domestic consumption and the pulp and paper industries are not in balance.

Despite the potential for private markets to create recycling programmes public agencies are setting up recycling schemes. Mandatory recycling schemes do exist in Denmark. They are targeting the organization of secondary fibre collection at local level:

- Public institutions are obliged to organize source collection of paper waste when the amount exceeds 100 kg per month (put into force 1988).
- It is mandatory for municipalities to organize a collection scheme for household-sorted paper waste from communities with more than 2,000 households and packaging paper and paperboard from the distribution sector, e.g. shops (put into force 1990). Offices and production facilities have been included in the schemes on a voluntary basis by some municipalities.

The Danish legislation is a mandatory provision of the collection systems merely facilitating a voluntary collection of paper recovered by households and firms[4]. It is estimated that about 100,000 tonnes of secondary paper is recovered in the mandatory collection schemes. This does not imply that all the mandatory recovery is not economically viable. Initially the mandatory schemes imposed a substantial cost on the municipalities because of an excess recovery and the low market prices for secondary fibre. There were two prime reasons for the lack of economic viability of the recovery schemes:

- The excess recovery of German secondary wood fibre was exported (dumped) and depressed markets of secondary materials in neighbouring countries.
- A horizontal integration of the traders purchasing the paper recovery with those processing secondary fibre also depressed the prices. The market distortion was investigated in Denmark by the *Board of Competition* (Konkurrencerådet 1992).[5]

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[4] The firms have an opportunity costs of waste disposal in Denmark. The waste disposal costs were in 1990 between 150 and 350 DKK per ton with an average cost of 250 DKK per ton (US$ 50 per ton) including a waste charge of 130 DKK per ton (DEPA, 1991).

[5] The price levels and access to the market of secondary fibre were analyzed by the *Board of Competition*, and the conclusion called for an enhanced competition to reduce rent dissipation and market access. The retail prices of secondary fibre by the involved firms have since been monitored and made public (from 1995 the firm specific prices are no longer available to the public).

[6] The reasons for the growing prices in the secondary wood fibre markets are: (i) a shift in the business cycle, (ii) large investments in the secondary fibre processing facilities of Central Europe, and (iii) secondary fibre is a globally traded commodity and exports to South East Asia has increased substantially.

The recent global price increases on secondary wood fibre[6] and the enhanced competitiveness on the domestic markets resulted in substantial price increases.[7] The economic viability of recycling schemes has improved significantly during 1994.

A distinctive feature and circumstance of the Danish market for secondary wood fibre is elucidated in a comparison with other countries with similar or distinctive features. In Table 2 the per capita production and consumption of paper and paperboard for some countries is compared along with the recovery and utilization of secondary wood fibre.

Table 2 shows that the per capita consumption of paper and paperboard in Denmark is at the higher end of the scale and the production at the lower end. It is seen that the Netherlands and Germany have a per capita production of paper and paperboard larger than in Denmark, yielding a higher recovery rate. The utilization rate, being a function of the capacity of the paper industry, has a strong influence on the recovery rate while the recovery has less influence on the utilization except when the secondary fibres are marketed below recovery cost, i.e. dumped. A policy to enhance recovery will not increase the utilization significantly, while a policy to enhance the utilization will push up the recovery rate without market distortions. A Danish regulation will not be able to increase the large utilization while the low recovery rate is what meets the eye. The reason why the Danish recovery is low compared with other countries is a lower share of *mill-broke*, and a policy merely to increase the *post-consumer* recovery further seems to be irrelevant without a development in the paper industry.

Table 2. A comparison of the paper and paperboard production, consumption and recovery in some countries.

	Paper and paperboard		*Secondary fibre*	
	Consumption	*Production*	*Recovery*	*Utilization*
	kg / cap.			
Denmark	240	63	85	52
Germany	200	164	105	91
Netherlands	209	187	113	131
United Kingdom	167	89	52	26
Finland	292	1,815	83	100
Sweden	238	965	105	146

Source: UN-ECE/FAO (1994a, 1994b)

The net trade of paper products in volumes has already been outlined. When it comes to the actual value of the trade the amount is revealed, and the potential cost savings originate from a domestic processing of secondary wood fibre. In Table 3

[7] During 1994 the prices of *mixed paper grades* have increased from about 0 DKK per ton or less to about 500-600 DKK per ton (at the mill gate). And the prices for *newsprint* recovery has doubled. The Danish prices are still low compared with Germany due to, e.g. a difference in the paper industry structure, and the markets are not completely integrated due to the cost of transportation.

the Danish trade balance for wood products is presented. In total there is a net export when the wood based furniture is included. Whether furniture should be balanced with the trade figures of forest products in general can be questioned. The large trade deficit in paper and paper products is worth noting because it is from this substantial amount gain originates from augmenting the level of recycling.

Compared with other nations Denmark is a large net importer of paper products even in absolute terms and rather large in the per capita comparison (Table 4).

Table 3. Forest products: Danish foreign trade (1992).

		Import	Export	
		10^{9} DKK		[import:export ratio]
(1)	Sawnwood and roundwood	3,0	0,6	5:1
(2)	Paper and paperboard	7,9	2,8	3:1
(3)	Other wood based products	2,0	3,0	1:1‰
(4)	Furniture (wood based)	1,7	10,0	1:6

Source: The Foreign trade statistics from the Danish Statistical Agency.

Table 4. Paper and paperboard - Foreign trade (1992).

	Net-import	*per capita*
	million US$	US$ / cap.
Denmark	973	18
Germany	851	1
Netherlands	434	2
United Kingdom	3,395	5
Finland	-5,679	-1,12
Sweden	- 5,044	-58

Source: UN-ECE/FAO (1994a)

Imported commodities should only be substituted by a domestic production if the production resources cannot yield a larger return in another production. The Danish import of paper cannot be completely avoided because there is no virgin fibre resource base. The only resource that can be developed for a domestic production is the recovered secondary wood fibre. The trade figures reveal that there could be a substantial gain from a more efficient use of secondary fibre, and in comparison with the Netherlands and Germany it may be positive if the domestic paper industry is developed. The large Danish trade figures also disclose that there is a large flow of wood fibre into the country being added to the flow of solid waste if not reused. An assessment of the recovery and utilization of secondary wood fibre reveals that among European countries Denmark belongs to a group of nations with limited availability of forest resources but with substantial consumption of paper and paperboard. Furthermore there is practically no industry pulping virgin fibre or processing basic paper and paperboard. Denmark is depending on imports of paper and paperboard for final consumption and conversion. It can initially be emphasized that:

- It is remarkable that the main impact of increased recovery and utilization of secondary wood fibre probably are on the foreign trade balance.
- The Danish case shows a rather distinctive division of the environmental impacts between nations because almost the entire consumption of virgin fibre based paper products is imported. The environmental impacts from the use of forest resources and the processing of virgin fibre are found abroad, i.e. outside the Danish jurisdiction for environmental policy.
- The origin of the recovered wood fibre is of importance when the environmental and economic impacts are assessed. The environmental focus is on the *post-consumer* recovery while value, mass, homogeneity and pureness increase when the recovery is *mill-broke*, e.g. *home scrap* (within processing unit) or *new scrap* (in the conversion). A relatively large share of the recovery in Denmark is post-consumer recovery.
- The Danish capacity for paper recovery and processing of secondary wood fibre is restricted by the nonexistence of a paper industry. Virgin and secondary fibre are close substitutes in several paper products, so the existence of a paper industry would result in a larger demand for secondary wood fibre.[8]

The characteristic for Denmark is that a rational policy for secondary wood fibre would be founded to a larger extent on issues of a trade policy and the mobilisation of domestic raw material rather than on the environmental impacts. The environmental concern could be addressed through, e.g. a purchasing clause targeting an environmentally acceptability of the imported production to the extent allowed by the EU completion rules. It is thus a restricted possibility for a Danish environmental legislation to address environmental issues outside its jurisdiction, i.e. a recycling policy may not be feasible. The requirement for governmental interventions for environmental protection reasons seems to be limited when the environmental impacts addressed are found abroad. It is furthermore of particular interest that the recovery in Denmark to a relatively large extent includes post-consumer recovery. Despite a large population density and environmental legislation targeting an enhanced secondary fibre recovery, the main constraint for further recovery

[8] This may, for example, be an explanation why the recovery rate in Sweden is about 10 percentage points above the EU average. It is not only because of the environmental legislation but also due to the large paper industry. The large export based paper industry has a large mill-broke flow compared with the domestic production. The large recovery rate (recovery/domestic consumption) in Sweden is a trivial figure compared with countries with a small pulp and paper industry. The relevant recovery rate for comparison would be the post-consumer recovery only.

appears to be the limited demand from paper industry. The recovery rate in Denmark may be at the lower end in a comparative study, but the *post-consumer* recovery rate is probably at the higher end.

2. The Danish action plan for increased recovery of secondary fibre

There are no recovery targets in the legislation while a *Danish action plan for solid waste and recycling* includes a target recycling rate from the current level (39 per cent) to the level of recovery rates in the Netherlands (55 per cent) and Germany (50 per cent). These two countries, however, have a more developed paper industry, so the recovery rate can also be extended simply by expanding the Danish paper industry while the *mill-broke*, since an increase of the recovery of *post-consumer* waste seems to be infeasible. A mandatory recovery target is a distinctive policy but it is not always a desirable instrument:

- A recovery target imposes a market distortion if the recovery cannot be utilized, i.e. markets of secondary fibre does not clear when supply exceeds demand. A market distortion occurs because the opportunity costs of the recovered fibre is not the marginal recovery costs (since recovery is mandatory) but the marginal disposal costs. The target is biased in the attempt to reduce the amount of paper waste when the markets for secondary fibre as a result is being distorted.
- It is a mistaken regulation to control the *relative* recovery rate since the environmental regulation have diminished the differences in the environmental load of virgin and recycled fibre, i.e. it is the production cost difference rather than the environmental impacts that differs. A more effective environmental regulation would be to control the *absolute* paper and paperboard consumption, e.g. with quotas. Further it should be included that secondary fibre once were introduced as virgin fibre in the fibre pool.
- The target does not take into consideration that *mill-broke* in the Netherlands and Germany constitutes a relatively larger share of the recovery due to the existence of a substantial paper industry.

A project initiated by the Ministry of Environment (in 1992) investigated the environmental and economic impacts of recycling and incineration of secondary wood fibre. The project was carried out by consultants and the ministry officials (i.e. not a research project). The final project was scheduled for spring 1993, but a preliminary draft was not released until January 1995 (DEPA 1995). The working papers were confidential and the project has in general been politically flawed and misrepresented towards sectorial interests. The methodology of the project has been scenario analysis of mass-flows with aggregated environmental impacts supplemented by an elementary economic analysis (adjusted factor prices). There was no economic assessment of environmental impacts, not even in terms of opportunity costs, so despite its title the project was not based on environmental economics at all.

Table 5. Paper recovery action plan.

	1,000 m.t.
Consumption	1,193
Recovery	467
Recovery rate	(39.1 %)
Governmental Action Plan on Solid waste:	
Target recovery (of present consumption)	676
Target increase in recovery (of present consumption)	+ 209
Target recovery rates:	
- newsprint	(172 □ 217 = 45) (90 %)
- mixed paper	(115 □ 236 = 121) (40 %)
- corrugated cardboard	(104 □ 147 = 43) (80 %)
Current mandatory recovery schemes:	99
- newsprint	(54)
- mixed paper	(27)
- corrugated cardboard	(18)

The scenario investigated an increase in the recovery rate and a utilization of the secondary fibre for the secondary fibre drawn from either energy recovery (A) or solid waste disposal (B). In another scenario (C) the impacts of energy recovery of the presumed collection of paper in the current mandatory recovery schemes were analysed.

Scenario 0: The recovery of paper and paperboard in 1992

Scenario A: Increased recovery according to the action plan (+ 209,000 m.t.). The increase in recovery results in a reduced waste incineration (and energy recovery)

Scenario B: Increased recovery according to the action plan (+ 209,000 m.t.). The increase in recovery results in a reduced solid waste disposal. When *all* paper and paperboard presently being disposed is recovered, the remaining part reduces incineration (and energy recovery)

Scenario C: A reduction in recovery equal to the present mandatory schemes (-99,000 m.t.). The reduced recovery is incinerated for energy recovery.

The results reveal that the main impacts are due to the economic consequences (Table 6) being exposed mainly by a shift in the trade balance. An increase in recovery provides an economic gain while increased energy recovery has an economic cost. The appointment of the environmental impacts is between different nations, e.g. the imports are all assumed to arrive from Sweden. The global economic benefits are not accounted for, viz. there may be a loss to the Swedish forest industry from an increased Danish recycling.

Table 6. Economic consequences.

Socio-economic welfare change (adjusted market prices): Discount rate 3 % and period of 15 years			
NPV (social welfare gains) 10^9 DKK			
	Scen. A	Scen. B	Scen. C
Newsprint	3,167	2,925	- 3,778
Mixed paper	1.666	1.072	- 361
Corrugated cardboard	343	136	- 144
Total	5,177	4,133	- 4,283
NPV (savings in foreign capital) 10^9 DKK			
	Scen. A	Scen. B	Scen. C
Newsprint	6,799	6,839	- 8,098
Mixed paper	3,756	3,869	- 664
Corrugated cardboard	914	963	- 403
Total	11,469	11,671	- 9,165

3. *On the methods for analyzing the economic and environmental consequences of recycling*

A few comments on the methods for analyzing the impacts of recycling are compelling. The purpose of an analysis is to establish an improved information basis for decision-making. But a biased analysis emphasizing the environmental impacts or pursuing sectorial interests results in incomplete information. Among the methods used for analyzing the impacts of wood fibre recycling schemes three main types are distinguished:

- *Mass-flow analysis:*
  - The mass-flow analysis is simplistic (understood by politicians but unrealistic in reality)
  - It is for example used for assessing a *volume*-based change in the demand for virgin wood fibre.
- *"Life-cycle" analysis:*
  - A guideline for policy targets but more applicable at the firm management level.
  - The different environmental impacts cannot be compared.
  - The impacts are assessed as an average value, i.e. there is no information

provided about the impacts of marginal changes in the production and consumption levels.
  - A LCA can eventually be used for designing the criteria of an "eco-label".
- *Economic analysis*
  - The general (and partial) economic equilibrium analyses are the feasible solutions.
  - The effectiveness of an instruments is determined by the relative costs.
  - An economic analysis can be a guideline for policy *implementation*.
  - Economics can in particular consider the external impacts, i.e. either attaching a value (e.g. through incentive charging) or establish a regulation addressing the opportunity costs.

It is important to realize that even though an analysis show that one policy is more or less preferable than another it must be considered how the favourable outcome may be achieved. When one policy is determined to be the most preferable to society, it is not likely to be preferable to any interest group, e.g. the forest sector. It can therefore be cumbersome to make a policy. In that case it does not seem to worthwhile having a policy justified by fragmented argumentations supporting particular interests. One approach is to consider whether a policy is in fact required. It is shown in Table 7 that only when external costs are present a policy regulation seems to be justified. The possible gains have to be weighed against new conflicts and policy failures, and the allocation of the financial costs and benefits should not be made by an environmental policy but more explicitly through, e.g. the fiscal policy.

Table 7. Social costs and benefits from paper recycling.

		Social costs and benefits	
		Financial	*External*
Recycling	*Benefits*	- market value of recovered paper fibre - saved cost for purchasing virgin fibre material	- reduced volume of municipal solid waste - reduced environmental load from processing pulpwood
	Costs	- collection and processing of recovered paper - reduced quality of recycled paper, i.e. risk of technical breaks in paper production - (possibly) investment in environmental technology	- environmental cost from collection and reprocessing of recovered paper - households' time and effort - impacts on forest resources, i.e. price depression and surplus of virgin fibre

4. *The "burning" question: Energy recovery or recycling ?*

There are gains from diverting secondary fibre from the waste flow equal to the avoided external costs. Even with no external costs there are rational business economic reasons for recovering wood fibre and utilize the secondary fibre for another product cycle or for energy recovery. The final use of secondary fibre, once recovered, is the *burning* question of energy recovery versus recycling. The energy recovery option was in particular promoted when the secondary products prices were low or even negative along with the mandatory recovery schemes in operation. Since incineration is not designated as a recycling option, energy recovery does not account in a recycling target. The prices of secondary wood fibre have increased, and the energy recovery option is less favourable to the collectors of secondary fibre. The forest lobby, however, still emphasizes the energy recovery option because fibre recycling substitutes virgin fibre input while energy recovery does not. The shift in the interest of energy recovery following the increase in the price of secondary wood fibre reveals the regulatory importance of the price mechanism and market incentives.

There is some attraction to market allocations generated through a *general economic equilibrium*, i.e. an outcome based on the prevailing prices. The key problem is to ensure that the external costs are minimized and eventually internalized through, e.g. environmental charges. The economics solution to the *burning* question is analyzed together with an approach assessing the environmental impacts, and as an example of environmental impacts the energy balance is used.

4.1. Economics of recycling or energy recovery

The marginal benefit from the alternative options, i.e. recycling or energy recovery, should determine whether the secondary wood fibre is diverted from the waste flow at all. The opportunity cost from not recovering the fibre equals the cost of not using the best alternative, i.e. substituting virgin fibre or the alternative fuel source less the avoided recovery costs. The marginal opportunity cost can be derived from *not* recycling secondary fibre for either of the two alternatives:

- A substitute of virgin fibre: $MOC_1 = MC_{VF} - MC_R$
- An alternative fuel: $MOC_2 = P_F - MC_R$

Where: MC_R = marginal cost of secondary fibre recovery
MC_{VF} = marginal cost of virgin fibre
P_F = the price of the alternative fuel[9]

[9] The fuel price is in equivalent fuel units. The fuel substitution is assumed to be inelastic, i.e. the amount of energy recovery from secondary materials cannot shift the fuel price.

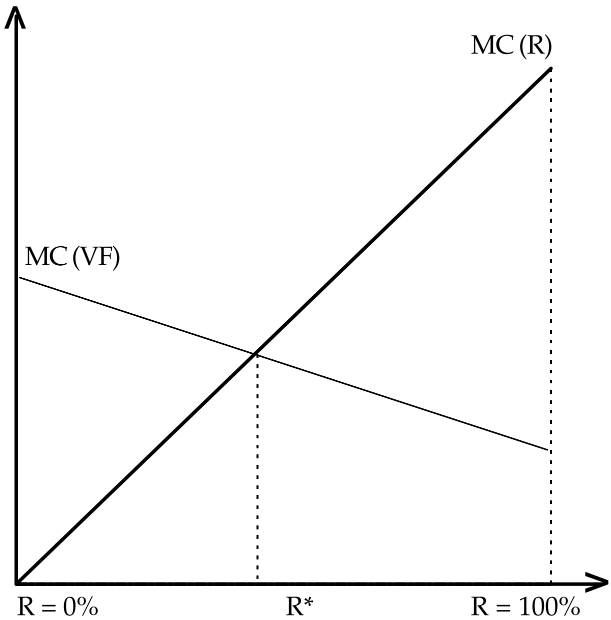

Figure 3. The optimal recycling level R*.

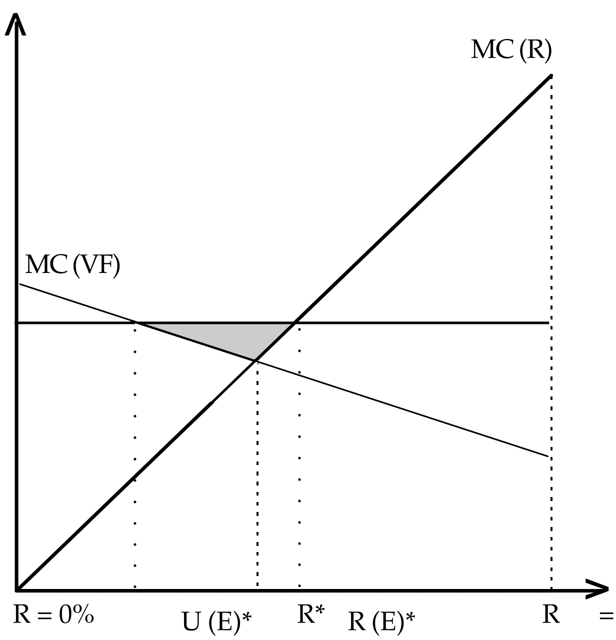

Figure 4. The optimal recovery (R_E*) and recycling (U_E*) level with an energy recovery option. The shaded area is the welfare gain of the energy recovery option.

The optimal level of recycling with no energy recovery (R^*) is shown in Figure 3 according to a simple rule: $MOC_1(R^*) = 0$.

The space between the two vertical axes is the total fibre consumption, and the converted supply curve (marginal cost) for virgin fibre is the demand for secondary fibre. The cost curve for virgin fibre is downward sloped because it is assumed that the level of utilization of secondary fibre can influence the price of virgin fibre. When energy recovery is also considered it is obvious that energy recovery is not economically viable if the equilibrium price of recycling exceeds the cost of the alternative fuel, $MC(R^*) > P_F$. If the price of the alternative fuel is larger than the equilibrium price, two economically induced shifts are contemplated:

- The *recovery rate* will increase ($R_E^* > R^*$) and the increased recovery will be incinerated for energy recovery. The equilibrium is determined by a simple rule: $MOC_2 = 0$. If $P_F > MC_R$ secondary wood fibre will also be collected for energy recovery.
- The *utilization rate* will decrease ($U^* > U_E^*$). Part of the secondary fibre already recovered will shift from being recycled to energy recovery, i.e. lowering the utilization rate. The optimal recycling level is determined by a decision rule: $MOC_1 = MOC_2 \rightarrow MC_{VF} = P_F$. The recovery of secondary fibre is used where the cost savings from the avoided use of the substitute (virgin fibre or the alternative fuel) is the largest.

In Figure 4 it is shown how an option for energy recovery increases the recovery (R_E^*) and reduces the utilization of secondary wood fibre for paper and paper-board (U_E^*).

It is a precondition that the cost of the alternative fuel is larger than the equilibrium price (for a fuel equivalent) in the market of secondary products. It can further be concluded that:

- The energy recovery is constrained not only by the price of secondary fibre but also by the price of virgin fibre. The secondary fibre has an opportunity cost when virgin fibre is not substituted but used for energy recovery instead.
- The market is able to adjust to the relative prices and also to divert secondary fibre to energy recovery or recycling. A regulation on the use of the secondary fibre is only relevant if there are substantial *differences* in the external costs from recycling compared with either energy recovery or virgin fibre processing and consumption. There is no need for a regulation restricting the energy recovery from secondary fibre.
- Environmental charges can be used to internalize the external costs. A charge on the alternative fuel will decrease U^* and increase R^*. A fee on virgin fibre will increase U^*, while R^* will not change. A subsidy for the recovery of secondary fibre will increase R^* while U^* is unchanged if energy recovery is economically viable.

4.2. *An energy analysis of recycling*

An indicator of the environmental impact could be the energy budget of recycling versus energy recovery. Examples explained by Byström and Lönnstedt (1995) compare energy recovery and fibre recycling for office paper (chemical pulp) and newsprint (mechanical pulp). (See Figures 3 and 4 in page 184 of these Proceedings.)

The comparison apparently reveals an advantage of energy recovery compared with recycling in terms of resource input and output. This result, however, can be reconsidered:

- There is a boundary problem of the energy analysis due to the difference in the input of wood. When the energy recovery option is preferred it is due to a larger throughput of biomass. The difference in the input of wood could be converted to heat (18 GJ heat per ton). The energy of the biomass can be recovered without an initial processing for paper.
- The energy and fibre recovery options are not directly comparable because they are connected. Recycling is not a substitute for virgin fibre, because the secondary fibre once were virgin. And the recycling of secondary fibre does not exclude a subsequent energy recovery.

The study by Byström & Lönstedt (1995) does not take into account that the cradle of recycled fibre *is* virgin fibre, and the grave of recycled fibre *could* be energy recovery. The flows in Figures 3 and 4 (p. 184) are thus not comparable without a similar cradle and grave, but the values can be used for comparison taking the raised points into account. A model is used where 1 ton of paper is produced in each of two subsequent periods. The cradle and grave become similar for both alternatives which makes the alternatives comparable:

Alternative (A): Energy recovery

period 1: virgin fibre –> energy recovery
period 2: virgin fibre –> energy recovery

Alternative (B): Modified wood fibre recycling

period 1: virgin fibre –> recycling
period 2: recycled fibre –> energy recovery

The result of the modified comparison of recycling and energy recovery is that the input of wood is less for the recycling alternative (B), and so is the input of process energy based on electricity. There are net savings of 0.6 GJ electricity for office paper and 13.7 GJ for newsprint. The net output of heat energy of the energy recycling alternative (B) compared with the energy recovery alternative (A) is 11.15 GJ for office paper and 2.9 GJ for newsprint. The difference is due to a larger throughput of wood of the energy recovery alternative, and the boundary problem can be solved by transforming the difference in wood consumption into heat equivalents, e.g. the heat requirement for paper making is supplied by burning biomass.

Table 8. A comparison of inputs and outputs for the recycling and energy recovery alternatives.

	Alternative A Energy recovery	*Alternative B* Recycling
Office paper		
• input	4 ton wood 10 GJ electr.	2.3 ton wood 9.375 GJ electr. 7.95 GJ heat
• output	23 GJ heat	11.5 GJ heat + 30.6 GJ heat (from 1.7 ton wood)
Newsprint		
• input	1.88 ton wood 21 GJ electr.	1.08 ton wood 15.7 GJ electr. 7.1 GJ heat
• output	23 GJ heat	11.5 GJ heat + 14.4 GJ heat (from 0.8 ton wood)

It seems plausible to solve the boundary problem by including the energy value of the saved wood resources, i.e. assuming the saved wood resource can be used directly for energy. And when considering the life-cycle of the wood fibre it seems evident that the energy budget with the figures presented by Byström & Lönnstedt (1995) favours the modified fibre recycling rather than energy recovery though an opposite conclusion is reached in the original paper. In the example it seems preferable to save wood resources rather than energy when wood is transformed directly to energy.

5. *The impacts on forest resources from an increased recycling*

Most forest sector interest groups are concerned about the reduced volume of wood consumption from the replacement of virgin fibre by secondary fibre. The efficiency gain at the pulp mills (an increased output/input factor) and the shifting business cycles also influence the demand for virgin wood fibre. The impact on the forest sector is thus not determined by the volume of the pulpwood market as such but by the resulting price equilibria and the general economic equilibrium. It is the price dynamics and not the presumed withdrawal of a share of the market volume that is at stake for the forest sector. It should further be considered that:

- The growth in consumption of paper and paperboard is ignored whereby the reduction in the wood consumption is overstated

- The efficiency gains in the pulp processing and paper industry have similar impacts on the consumption of virgin fibre as has the use of secondary fibre.
- Recycled wood fibre is an economic resource with a global market, and it provides an option for domestic processing in Denmark. There are social costs from not recovering wood fibre and reuse secondary fibre efficiently, i.e. where the most expensive substitute is avoided.
- An assessment of the impacts based on a mass-flow rather than economic analysis is erroneous because prices rather than quantities are the crucial topics.
- The impact of Danish recycling is only on foreign forests, and thus outside the realm of national policies. The Danish forest sector is influenced by the price distortions inflected by a general increase in the utilization of secondary fibre.
- Maximum production of pulpwood is not a social objective, i.e. the forests are not managed for forests' sake alone. If the thinning volumes cannot be utilized for paper other means of use and forest management should evolve. The virgin fibre replacement is essential so a substantial demand for virgin fibre will remain. The argument that every ton of newsprint from, e.g. Canada pushes out one ton of, say, German paper with a large content of secondary fibre is so plausibly deceptive that it virtually defies a logical answer. A constant closed-circuit recycling of the home product will make anything but dust.

The Danish consumption of paper and paperboard is composed by imports, domestic recycling and fillers, imported pulp and a small amount of Danish fibre. Figure 5 shows the composition during the past.

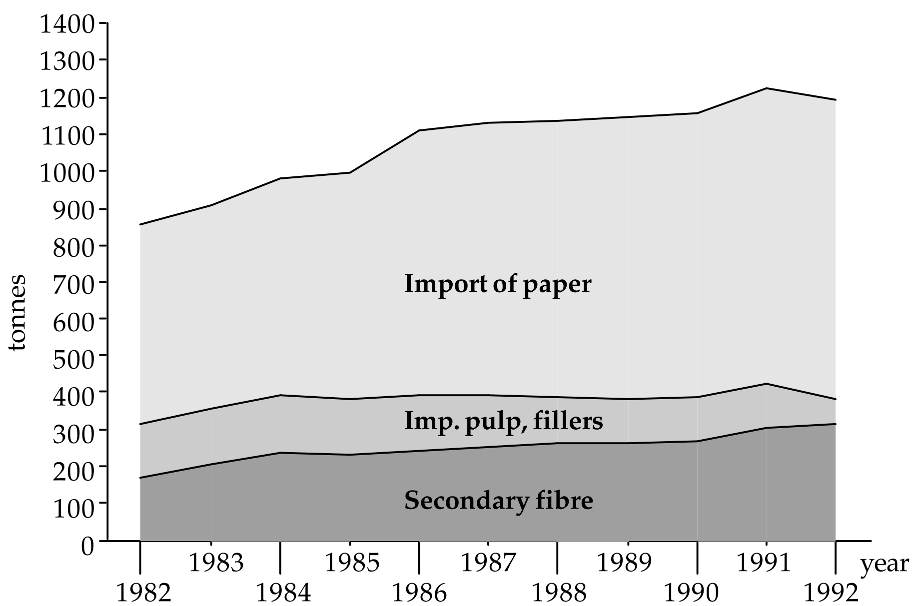

Figure 5. The Danish consumption of paper and paperboard (1982-1992).

The trend from 1982 to 1992 is shown in Table 9. With a growing volume of the market there is not an *absolute* reduction of the wood consumption but merely a price depression from an increased competition and a lower *relative* market share. The consumption of paper and paperboard is growing relatively slower than the consumption of secondary fibre recovery, but the total consumption of virgin fibre has not declined.

Table 9. Paper and paperboard - Denmark (1982-1992).

	1982	1992	Δ	Annual growth
		1,000 m.t		*per cent*
Consumption	858	1.193	335	3,4
Production	315	380	65	1,9
Recovery	234	424	190	6,1
Utilization	169	315	146	6,4

Source: Rendan (1993)

The annual growth rate for the consumption of paper is less compared with the recovery and utilization, but a relative measure cannot disclose an absolute increase in total consumption of virgin fibre. The estimate in the box shows that there might have been an increase in the total volume of virgin fibre use. The volume of virgin fibre consumption could have been larger without an increase in the use of secondary fibre.

Paper recycling and the growth in total paper consumption - a theoretical applicatio

Utilization rate: X_t

Paper Consumption: C_t

Consumption of recycled fibre: R_t

From T=1 to T=2:

$\Delta R_{1\to 2} = (X_2 * C_2) - (X_1 * C_1) \Rightarrow$

$\Delta R_{1\to 2} = X_1 * \Delta C_{1\to 2} + \Delta X_{1\to 2} * C_2$

Denmark 1982 - 1992:

$\Delta C_{1\to 2}$: 335,000 m.t.

C_2: 1,193,000 m.t.

X_1: 30 %

$\Delta X_{1\to 2}$: 10 % (assumed)

$\Delta R_{1\to 2}$: 219,000 m.t.

An estimated increase in the *annual* consumption of **116,000 m.t.** (virgin wood fibre, additives, etc.)

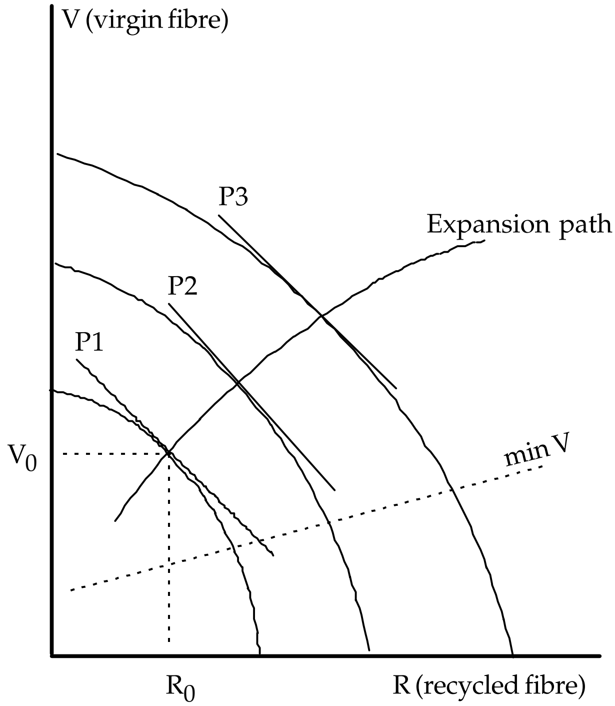

Figure 6. A theoretical expansion path for the use of secondary and virgin fibre.

The difference between a change in the volume of recycled fibre and virgin fibre is the first item when assessing the impacts of recycling on forest resources. With a growing consumption of paper it can be discussed whether the *absolute* or the *relative* increase should be furnished with virgin fibre. In the expanding wood fibre market it is a question whether the forest sector can expect an expanding use of virgin fibre. The question, however, does not lead to useful answers because of most relevance is the relative prices of virgin and secondary fibre. The forest sector is inclined to assume there is a loss of market shares simply because the volume of secondary fibre is growing while the loss may be in relative not absolute terms. Figure 6 shows a theoretical expansion paths for the composition of virgin and secondary fibre dependent on the relative prices. It seen that the use of virgin fibre exceeds the initial level (V_0) even with a growing use of secondary fibre.

The volume of pulpwood on the market will be cleared at prices reflecting the opportunity costs of competing substitutes, and an increased competition from secondary wood fibre results in lower market prices. The Forest & Nature Agency (1994) has analyzed the impacts of recycling in a static analysis of quantity substitution, i.e. one tonne extra of secondary fibre pushes away one tonne of virgin fibre. Because the analysis ignores the existence of a market mechanism and the growing consumption it has no relevance to the consequences of recycling on forest resources. It is in fact misleading to presume that one tonne extra of secondary fibre pushes away one tonne of virgin fibre when the total fibre consumption is increasing.

In Figure 6 this approach is equal to an assumption that the expansion path is vertical through [R0; V0], and it is obvious that it results in a gain to the forest sector but a social welfare loss.

The impact of increased recycling not entailing a substantial state intervention is thus increased competitiveness and a social welfare gain. The requirement of a governmental regulation must be carefully examined and it should only be exercised when the external costs are creating a market failure. The forest sector may get an increased competition from an efficient use of wood fibre. But the apparent loss to the forest sector is accompanied by a social welfare gain due to an increased competition between secondary and virgin fibre.

6. *Discussion*

A policy for enhanced recycling can be justified when there are expected welfare gains from:

- Reducing the market failures derived from external costs and benefits, e.g. the control of pollution damage.
- Adjusting the structural market failures, e.g. organizing curb-side collection programmes or increase competition in the secondary materials markets.

In the Danish case there would also be a social welfare gain from a domestic production based on secondary materials when the alternative is imports, e.g. the value-added and multiplier components of the domestic production. It equals an increased foreign investments or the avoidance of industrial production moving abroad. A precondition is a recovery of the secondary fibre and processing for paper products. It is crucial that the markets for secondary materials can clear, i.e. that the market functions are not distorted. A problem has been the emphasis of policy regulation (e.g. the German Recycling Ordinance) on recovery (*supply*) rather than utilization (*demand*). The excess supply is exported and the result is dumping of secondary materials on markets in other countries. A problem with mandatory recycling it that other market failures emerge because the marginal cost does not reflect the recovery costs but an alternative option, i.e. what the collectors pay to get rid of the secondary fibre. In order to avoid a situation where it would be more cost-effective to landfill or export recovered secondary wood fibre instead of reusing it, governments could introduce policies which would reduce the supply of secondary fibre and/or increase its use (Laplante & Luckert 1993). An example of stimulated demand is legislation that requires newsprint to contain some percentages of secondary fibre. A solution is a switch to a recovery driven by demand-side policies, i.e. regulation on the utilization of secondary fibre though a regulation prescribing a mandatory content of secondary fibre. It can also result in market distortions and price differentiations (Linddal 1994). One solution is demonstrated for newsprint in USA where the mandatory recycling content is made tradeable, i.e. the cost of using secondary fibre is minimized across firms. A policy in Denmark cannot include higher targets on the utilization of secondary fibre since it is already very high and regulation thus considers the recovery. It is a feasible, but not a desirable policy.

A *life-cycle-analysis* is useful for managing production firms because it depicts the options for reducing the environmental impacts and improvements of the production. A LCA will aid the management in complying with environmental standards, but it is less useful for designing a policy or environmental regulation. If an environmental policy is forcing the *best available technology* (BAT) to be applied in the production processes, the result is minimized environmental impacts. And regulation could be much more effective if incentives can be established by adjusting market failures (separately and directly) in the *markets* of, e.g. energy production, paper making, forestry and landfills.

In the design of a policy instrument the objective must be visible and it should address the social cost and benefits. The aim of a policy is to minimize the adverse impacts from pursuing a desirable level of recycling. It is obvious that the forest sector and even forest research are to narrow minded in the assessment of the impacts of recycling on the forest sector. The emphasis of the mass-flow is, for example, bound to provide erroneous results mainly because the market supports an efficient reallocation. The shift in the economic general equilibrium may not be in favour to the forest sector, but an increased competition in the markets for inputs to the production and a reduced rent dissipation generate a social welfare gain. And who should bear the losses if society has foregone benefits from inefficient use of secondary fibre in order to sustain an excessive and above-cost use of virgin fibre?

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LIFE CYCLE INVENTORIES AND JOINED MATERIAL PROJECTIONS IN NATIONAL ENVIRONMENTAL PLANNING

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Abstract

The applicability of Life Cycle Inventory techniques and Joined Time Projection models to national material flow management is studied. The dilemma of system boundaries is first discussed. Results obtained from a subsystem LCI are indeterminate, yet a totally complete system is impractical. In addition, the objectives of national planning require that the system be limited to the nation. The static nature of traditional LCI's impairs their usefulness. Life cycle inventories and analyses serve well as an identifier of areas of improvement on a product's life cycle. Their applicability to regional or national environmental planning is however limited, because they are static, consider only one product, and that in the past time. Joint time projections of an industrial system are seen as more amenable for policy planning. LCI data is used as input to these projections, which consider complete systems and are capable of dynamic forward planning. The ability of joint time projections to include both environmental data and other decision factors, such as effects of a policy on investments and operating costs, imports and exports, and employment makes them a tool more suited for the needs of regional or national environmental planning.

1. National environmental planning through material flow management

In most countries environmental legislation has traditionally focused on protection, i.e. the prevention of hazards to human health and to the (local) environment. More recently, legislation has been introduced with the objective of improving sustainability. One example are the numerous recycling laws, ordinances and administrative rulings, which have been decreed in Europe and America in the past few years (Assmann 1993, Göttsching and Putz 1994, Laplante and Luckert

1993, Pento 1994). The purpose of these has been to direct a region or a nation toward sustainability by forcing the reuse of products or materials.

Advance planning of many of these laws and ordinances appears to have been so insufficient that they have in some cases produced more problems than solutions. For example, one of the main motives behind the German packaging ordinance of 1991 was the saving of landfill capacity in the country. The ordinance forced the raise of recovery rates of all packaging materials without providing a solution for their reuse. As a result, material began to accumulate in unofficial landfills and illegal dumps, and costs of the recycling system skyrocketed. In its early stages the ordinance probably caused more economic and environmental harm than good (Berliner Tagesblatt 1994, Buchner 1993, Economist 1994). The "garbage crises" in some areas of the United States were also the creation of unsuccessful policies which have been set by authorities on environmental grounds (Chilton 1992).

Traditional planning tools of economies, such as microeconomic analyses of markets, have proven insufficient in analyses of policies directed toward improving sustainability. As of now, it appears that future policies will have to be placed increasingly on some type of modelling of the flows of materials and products[1]. The authoritative German Enquete-Kommission "Protection of People and Environment" considers material flow analysis and management as the prime vehicles on the road to sustainable development[2]. On the national level these tools would provide information for actions to divert or close such material flows which waste resources or cause unnecessary environmental loads

A host of techniques for modelling national material flows and the environmental loads associated with them have been brought forward, such as Life Cycle Inventories (LCI) and Assessments (LCA) (Virtanen and Nilsson 1993, Daae and Clift 1994), Material Intensity Analyses (Schmidt-Bleeck 1993, Liedtke et al. 1993), Substance Flow Analyses (Udo de Haes et al. 1991, van der Voet et al. 1993), Material/Energy Balances (Ayres et al. 1989, Ayres and Norberg-Bohm 1994), Product Flow Paths (Bilitewski 1993, Putz and Göttsching 1993), Models of waste generation and waste flows (Baccini and Brunner 1990), Joined Time Projections (Pento 1994, 1995), and sectoral economic models with environmental variables (Zhang et al. 1993).

Two of these methods, Life Cycle Analyses and Joined Time Projections are analyzed here in regard to their applicability as tools for planning national environmental policy. The flows on printing papers in Germany is used as the application example.

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[1] The term material flows is used here to denote flows of both substances and products.

[2] Zur Konkretisierung und Umsetzung des Leitbildes einer nachhaltig zukunftverträglichen Entwicklung (Sustainable Development) ist eine Analyse der Stoffströme in betrieblichem, regionalem, nationalem und globalem Kontext erforderlich (Stoffstromanalyse). Entsprechende informationssystems sollen klare Konzeptionen zum Umgang für Lenkungsmöglichkeiten für die jeweils beteiligten Akteure geben (Stoffstrommanagement). Enquete-Kommission (1993), p. 18

2. *Selection of system boundaries*

There have been attempts of macroenvironmental planning through the simultaneous analysis of several large national material flows (Merten et al. 1994, Schmidt-Bleeck 1994). Until now, these analyses have been performed at a rather aggregated level, and their methodology and practicability and is still untested. The more common technique selects a subset of the flows by defining boundaries for each system which is to be modelled. In this approach the proper method would be to separate a subsystem, and to study all of its inputs and outputs with nature (SETAC, 1993). Unfortunately, the complexity and interrelatedness of many material flow systems, like those of the pulp and paper industry, makes even such an approach impracticable. The size of the resulting model explodes, the cumulative effects of errors and the unreliability of the gathered data begin to weaken its results, and the complexity of analyses combined with butterfly effects make it too unwieldy for practical use.

2.1. Product-based system boundaries

One material flow modelling approach limits the system to the linear flow of one product. In its simplest form such a system depicts a product's partial life cycle flow from the cradle to the customer's gate. Such models are generally considered a good tool for the identification of problem areas on the life cycle of a particular product at which an environmental improvement could be made. Industries and firms have been able to use LCI's of this kind successfully in their environmental planning to select suppliers, improve production methods, eliminate logistical problems and other unnecessary waste.

The applicability of product-based flow models to national planning is limited, and their results may lead to incorrect policies. In principle they can be used when the flows of different products of the industry are not appreciably mixed at any location and are independent of each other. For example, separate LCI's of newsprint, and magazine and fine paper grades are usable tools for national planning in those countries where the papers are either imported or are manufactured at different production units and are deposited after use to landfills. The cradles and the graves of the life cycles are well defined, the systems are separable in principle, and national policy can be used to steer each system independently of the others.

The use of product-based system boundaries is not good practice when the material flows are mixed and pooled. This is the case when different paper grades are made by the same production units, and when used papers are pooled in the collection and recycling system of old papers. The life cycle of a product in such a case can not be determined exactly, because it depends on the complete system of which it is a part. For example, the life cycle of newsprint depends on the amounts, furnishes and reuses of recovered old papers. Some collected old newspapers may be shipped to become raw-material of hygiene and technical papers, or board, some may be exported, and a part may be de-inked for reuse either in newsprint or magazine paper manufacture. The proportion which is used for what depends on very many factors, ranging from the demand of the various end products, to the prices of recovered papers relative to virgin materials, to the extent and accuracy of the sorting of the recovered papers.

The application of only a linear part of a product's life cycle as a basis of national policy may lead to suboptimization and even outright errors. One such analysis computes the linear life cycles of old paper to pulp and wood to pulp and shows that making newsprint of old newspapers consumes less energy than the manufacture of virgin paper (Tiedemann 1993). It is also clear that collecting old newspapers for recycling will reduce the amount of community waste which is placed into landfills. Together, these findings point out that both energy and landfill capacity will be saved with a maximal recovery and reuse policy. Yet, some analyses of larger systems show that such a policy would increase the total amount of solid waste (Pento 1994), would be detrimental to the environment in several respects (Virtanen and Nilsson 1993), and might not even provide the best energy solution (Kärnä et al. 1995).

Product-based LCI's may also be too unspecific for national planning. They calculate loads for a functional unit (SETAC 1993, 13) which, as an example, could be defined as a ton of newsprint at a publisher's gate. This form of calculation does not provide a national decision maker with sufficient information about the quantities and directions of flows which are to be managed by policy, neither about the actors who would be in the position to make the changes required by a policy. A modelling technique at the level of the industry or a nation would be preferable to the policy maker.

2.2. *Industry-based system boundaries*

LCI's have been adapted for national and regional environmental planning by calculating effluent, material, and energy inventories for a functional unit of an "average material flow". In this approach, all production and consumption units which handle the same or similar products are aggregated into one, and one or more of aggregates are bounded to form an industry. Virtanen and Nilsson (1993), in their ground breaking study analysed printing paper recycling in Europe by considering average flows of papers, and by counting the effluents, energy, and carbon balances affiliated with them. Similar calculations for the average life cycles of one or more products have been presented by Ebeling et al. (1993), Kärnä et al. (1994, 1995), Byström et al. (1994), and Clift et al. (1994).

The use of average data of the type effluent/ton of product, energy/ton, and material/ton confronts the user with a formidable problem of data collection and definition. For example, there can be tenfold differences in the effluent production/ton of product of different mills, and the definition of an average mill may be difficult because of this. Data of all production units which belong to an aggregate may not be available, and the data obtained may thus be skewed. On the other hand, the absolute errors of average figures might be smaller than those of independent mills, which are more affected by different conditions, capacity utilization rates and other factors.

First objective in setting the system boundaries for national planning is that either the total model, or one of its classifications must conform to the geographical area of the country. This separates domestic consumption and production from those of other nations, and facilitates analyses of environmental data together with other factors relevant for policy making, such as imports and exports, and domestic production. It is also good practice to set the boundaries of the subsystem of the industry in such a way that the material flows in and out of the system are as linear as possible, without recycling loops going out and coming back in. Figure 1 gives one example of an industry-based national system, that of printing papers in Germany. The incoming flows of material in this system are from nature to gate without return, and the outgoing flows are either to nature or one way linear to other production processes. For example, any old papers which flow to the manufacture of hygiene or technical papers or different types of board, or which are exported do not come back to the main recycling loop.

Industry-based LCI methods can be designed to model complicated material flow systems, which have recycling loops, multitudes of material sources and sinks, several types of production units, which combine materials to products and disassemble products to materials, as well as multiple consumption units. Recent advances in LCI modelling techniques and programs, especially in the one developed by Kärnä et al. (1995) provide the user with tools with which to prepare such extensive models using average data.

3. *Industry-based life cycle inventories as tools in national material flow planning*

The process of making industry-based LCI's for national planning is straightforward: define the functional unit to be measured and the boundaries of the system, analyze the material flows, construct the corresponding LCI-model, and calculate the inventory of materials, energy and effluents which is generated by the specified flows. The inventories make for a powerful tool of analysis and planning, especially when augmented with sensitivity analyses and sub-inventories for different parts of the model.

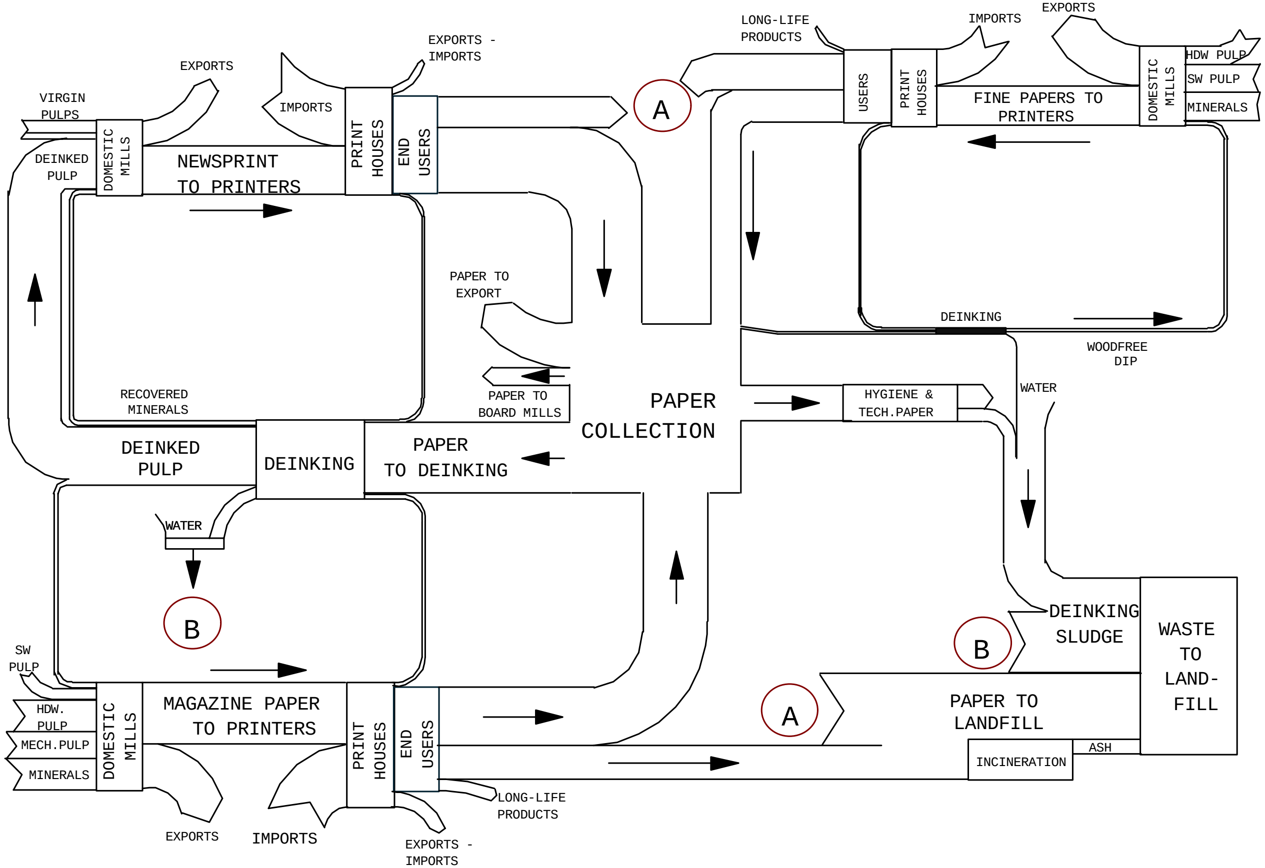

Figure 1. Material flows of printing papers in Germany in 1993 (Pento, 1994).

The static nature of industry-based LCI-models considerably reduces their value as a tool in national environmental planning. A static LCI counts environmental loads and energy and material uses on the basis of the material flows, which existed in the industrial structure of the past, not those of the future. Static LCI's enable the user to analyze the amounts of loads and the locations where they occur, but they do not facilitate the making of structured analyses of the effects of different policy alternatives, which could be considered feasible ex ante.

The basic problem of a static LCI is in its incapability of accounting for the combined effects of system changes. An LCI is constructed by taking the effluent/ energy/material figures of a mill operating in the industry in the past, and by assuming that the same mill operating in exactly the same way will have the same figures in the future. The effects of changes in the system make this assumption invalid. The yield of a de-inking plant makes for a good example. Consider a fictitious "average" German newsprint mill in 1994, when printing paper recovery rate was around 50 %. The mill used 100 % de-inked pulp, and had a raw-material composition of 60 % newsprint, 40 % magazine papers, and no mixed quality old papers. It could reuse most of the fillers in this raw-material into its paper, and had a yield of over 85 %. Consider then a policy which raises the recovery rates to 70 %, and where the recovered papers are used de-inked into newsprint manufacture. The yields of the same "average" mill will be drastically lower because of these changes. The composition of the raw-material will have to change because the increased recovery rate will produce more magazine papers and mixed qualities for the "average" mill. This will reduce the yield drastically in two ways. First, the yield of the mixed qualities is lower than that of the other used paper grades. Secondly, the proportion of fillers in the old papers will be so much higher, that the mill can use only a part of them into its newsprint, and has to put the remainder into waste.

Such effects of dynamic system changes on the material flows and their generation of effluents, and use of materials and energy must be a consideration to the national decision maker, who is interested in the total effects of a policy. A static LCI is not the best possible provider of the necessary information.

Second, current LCI-techniques do not provide for a policy's effect analysis. This can create huge unnecessary costs, when policies are put into effect using the society or an industry as an experiment ground. A good example of this is the German Verpackungsverordnung of 1991, and the results which it created. The ordinance decreed ever-increasing recovery rates and reuse rates for all packaging materials, without giving any consideration to the placement of the collected material. As a result, millions of tons of unwanted material were collected, and the finances of the national organizing body, the Duales System Deutschland (DSD), were repeatedly insufficient to secure proper end treatment for the collected material. The total cost of this experiment is not known to us, but the mere subsidies to the DSD range in many thousands of millions of DM. It is likely that a prior analysis of the material flows would have prevented these problems by pointing out the magnitude of the problem, and by indicating more suitable recovery rates and end-treatments of the collected material. (Buchner, 1993)

Another drawback of a static industry-level LCI lies in its incapability to incorporate in its analysis dynamic changes which are expected to take place in the system in the future planning period. There will obviously be changes in consumption patterns and amounts, industry will modernize their capital equipment, new technologies will be introduced, and collection and recovery systems may change. Such changes will affect all parts of the system: material flows, yields, energy consumption, and the production of effluents and waste. An LCI, whose average figures are based on some functional unit, made with the production equipments and technologies which existed in the industry at some time in the past will overestimate all environmental loads from effluent production to energy consumption. The history of industries shows consistent improvements, which are in most cases expected to continue in the future. An example in point is that of the amount of AOX in the waste waters of an old kraft pulp mill using active chlorine, compared with those of modified, or new mills who use no chlorine in bleaching.

The effects of changes could be built by constructing several static LCI-models using today's averages, and BATNEEC (best available technology not entailing excessive costs) of today and tomorrow. Even then, the dynamics of the actual change which are expected to take place in the system will not be shown by these LCI's, even though that these are of the liveliest interest to the policy maker. One of the most important tools in national policy is to advance such system changes which have environmental characteristics: new technologies, better capital equipment, improved collection and sorting methods, etc.

In summary, the environmental data of a static LCI is very useful as a basis of national environmental policy for it points out the amounts of effluents, energy and materials used and produced by the system. But it is deficient in the sense that it will not provide the planner the possibility of simulating the effects on the system by some environmental policy. For example, several communities in the U.S. have raised the recovery rates of old papers by law, and have found out that these laws have backfired in the form of glutted markets and illegal dumps. Such occurrences can be better avoided by making dynamic forward-looking analyses of alternative policies.

4. The needs of national environmental planning

National environmental planning must have several characteristics if it is to be successful. The first need is that there must exist a clearly defined object of policy. An object like a product or the environment is impracticable when the policy has to be put into action. Therefore, an object like an industry is preferred, because the firms of the industry have the tools and the organizations to make changes, and they can be either commanded or induced to take actions toward the desired goals (Soininvaara, 1993).

Any method of the national environmental planning must also be able to forecast the effects of what different policy alternatives might cause. A complete forecast of the future is not needed, but trajectories of the effects of different policies, as well as their sensitivity in reaching the specified goals.

A good method also analyses complete systems, as much as that is possible. In any case, separate analyses of interdependent subsystems is fraught with the risk of producing indeterminate results, and as a result, suboptimal policies. For example, a linear life cycle analysis of printing papers shows that their recovery and recycling will reduce the amount of solid waste produced, while a comprehensive analysis of the material flows of the printing paper industry show clearly, that this is not the case. The total solid waste produced actually increases when paper recovery rates are raised substantially (Pento 1994, Pento 1994a).

There is also a need that as many of the relevant decision factors as possible should be included the same analysis frame. A list of such factors includes the following:

- environmental considerations: use of raw-materials and energy, and output of effluents and waste
- economic factors: size of investments and operating costs, and the effects on different markets
- results on employment: amounts and types
- technical feasibility
- effects on international trade: amounts of import and export

Joining these factors into one analysis framework facilitates their commensurability when planning different policy alternatives. There are other factors as well which in theory could be included in the model but in practise the model would grow so much as to become too unwieldy to use.

5. *Joined time projection models in planning national environmental policy*

The Joined Time Projection (JTP) technique facilitates the dynamic analysis of the material flows of an industrial system, in which many factors change simultaneously over time (Pento 1994). This construction technique joins together a series of models, which each describe the material flows of a system in a given time period, such as a year. The models of different periods may be temporally connected with stock equations or like, or may be semi-independent, in which case there are only some or no intertemporal links between them. The technique is a type of quantitative scenario analysis, in which future projections are made of the parameters which largely define the annual material flows. Some of the parameters can be policy variables.

A Joined Time Projection model of the flow system of Figure 1 has been constructed to analyze the effects of paper recovery policies in Germany, specifically policies of compulsory recovery rates and fibre reuse to de-inking and incineration. The construction of the model proceeds from the base material flows of 1993. Projections up to the year 2000 can be made by specifying parameters to arrive at wanted scenarios. Consumption projections of paper grades determine the volumes of the system. Capacities of paper machines and de-inking facilities are projected, and serve as a basis in determining the amounts of imports and exports of papers and used papers, as well as a limiter to domestic reuse of collected papers. Technology projections are also made of yield changes and improvements in the processes which handle the flows. Finally, the most important projections are those of policies which are studied, such as used paper recovery rates

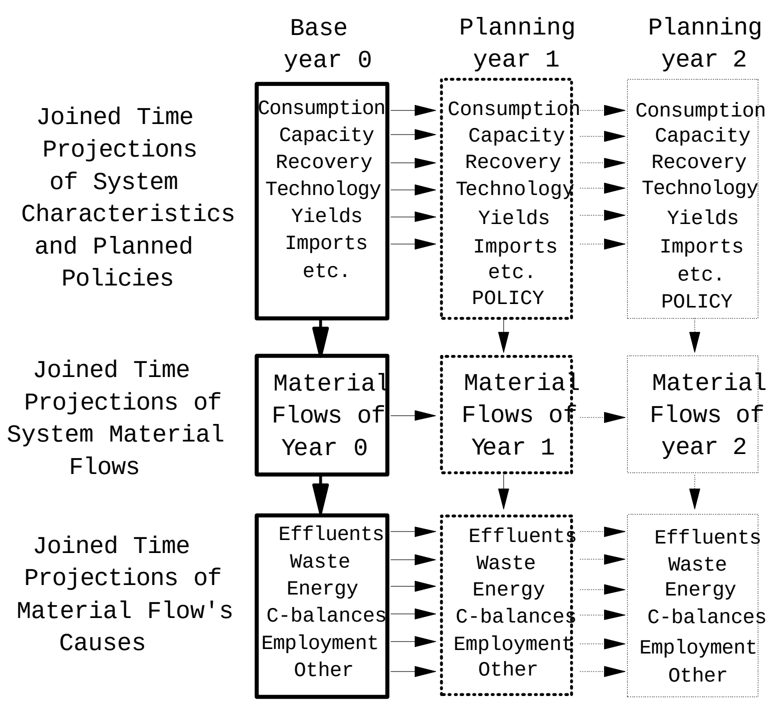

Figure 2. *The structure of a joined time projection model.*

The annual material flows are determined on the basis of the set parameters. The flows in turn are used as an input to calculations of their causes, such as the use of materials and energy, the effluents and waste produced, carbon balances, employment, imports and exports. A dynamic analysis is facilitated by setting the models side by side for a study of the changes over time.

A set of projected parameters commonly produces problems in the sense that the material flows in the annual models do not balance, do not make any sense, or create unwanted results. For example, a policy of a very rapid increase in used paper recovery and forced de-inking[3] may create unwanted large temporary stocks of material, because de-inking and at newsprint mill capacities are a limiting bottleneck. Sometimes disturbances are caused by market projections, for example in the case when projected domestic use of chemical pulp exceeds capacity and leads to massive increases in imports.

Two types of Joined Time Projection techniques are currently under development. The simpler approach constructs industry-level LCI models for a number of years into the future with the scenario technique, and joins their causes for a time projection. The material flow management modelling first analyses the development of the characteristics which define the material flows, builds separate models to simulate the flows for each year in the planning horizon. The estimates of the environmental, economic, commercial, and other causes which are generated by the flows are iterated and made after the flows are known, and are joined into a dynamic framework. These two development directions are already converging, and it is expected that JTP-techniques of the future will be material flow based LCI simulations, in which the environmental data is more or less automatically picked from an inventory.

5.1 The advantages and problems of the Joined Time Projection model

The main advantage of the Joined Time Projection technique is that it allows the user to make detailed and quantified projections and scenarios of the future. The JTP model facilitates greatly dynamic scenario analyses partly because of the model's capability to look forward in time. The time perspective can be very wide, and continually dynamic, in the calculations if that is demanded. Figure 3 shows waste production in Germany between 1993 and 2000 in two alternative scenarios. Scenario 1 assumes that no policy actions will be taken concerning the recovery rates or incineration of papers, but that the development will continue in a laissez-faire situation. Scenario 2 assumes three policy changes. Paper recovery rates are increased by decree to 70 % by the year 2000. The mineral content of all papers is slowly reduced to correspond to a minimal thermal value of 17 GJ/t. A substantial amount of lowest grade waste papers are incinerated, together with the increasing amount of de-inking sludge. The results of these policies onto the total amount of waste generated by type is visible in Figures 3A and 3B.

The Joined Time Projection model's holistic method allows to analyse the

[3] Policy forced de-inking = prohibition of incineration and exports of used papers.

Figure 3. Total waste produced by the paper recycling system in Germany in 1993-2000, thousands of tons.

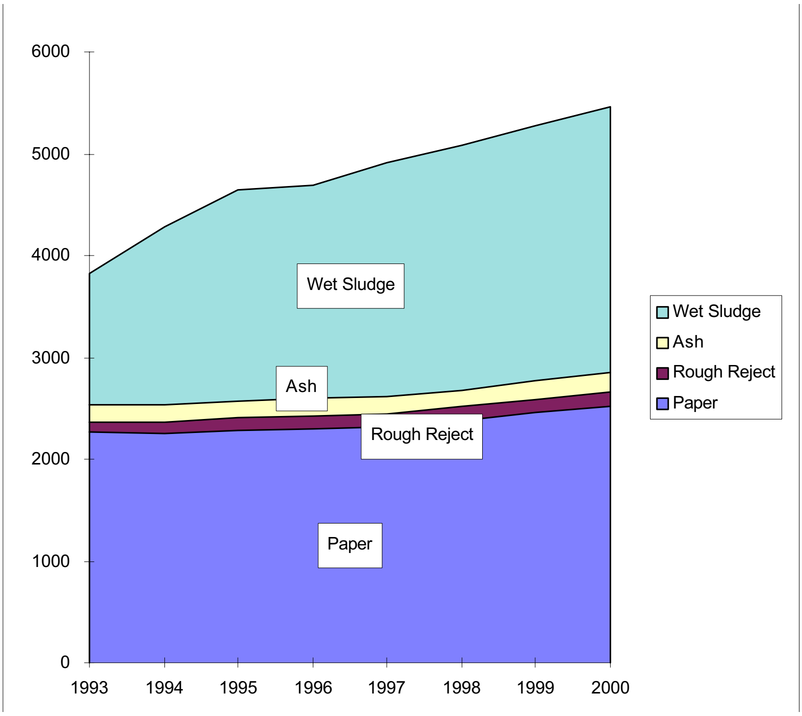

Figure 3A. No policy actions, "laissez-faire".

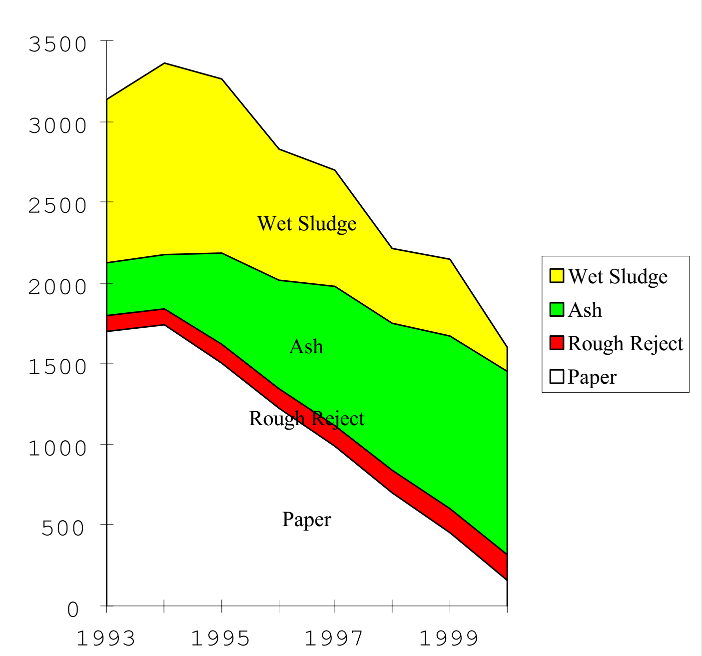

Figure 3B. Minimal thermal value of 17 GJ/t for papers, and increasing incineration of low quality paper with de-inking sludge.

relations of the research object with other related systems. The JTP model considers complete industrial not only one average product (like an LCA does).

The model also makes it possible to see clearly if, when, and where a particular policy will create disturbances and bottlenecks in material flows and markets. It makes possible to do analyses on techniques, technologies and capacity changes.

A major problem in JTP modelling is the lack of data, and the application of available data, especially that which pertains to environmental factors. A projection may show that material flows will be balanced when the furnishes of newsprint mills contain on the average 74 % of de-inked pulp. The availability effluent data for this kind of average is unavailable, and has to be estimated with rather subjective methods. On the other hand, the effects of possible errors in the estimates of the parameters and functions are minimized by a differential analysis over time, in which the actual figures are not of interest but rather the changes in the measured variables.

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ECONOMIC CONSEQUENCES OF INCREASED USE OF RECYCLED FIBRE IN THE NEWSPRINT AND MAGAZINE PAPER PRODUCTION IN NORWAY

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&
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Abstract

This paper analyses the consequences of increased use of recycled fibre in the newsprint and magazine paper industry of Norway. A regionalized partial equilibrium model is used for the analysis of four scenario alternatives regarding the use of recycled fibre. It is concluded that the harvest and price of spruce pulpwood will be lowered significantly if recycled fibre in the magnitude of 300 000 tons and more per year are used.

Introduction

Increased paper recycling is an important topic on the international environmental agenda. From an environmental point of view there are, at the outset, three main arguments for increased paper recycling: (a) To reduce the quantity of consumption waste; (b) to increase the utilization of wood by reducing the wood fibres, thus reducing the timber fellings; (c) to reduce the pollution and energy consumption. In addition comes, for some paper types, that increased use of recycled paper as substitute for pulpwood or pulp, might be profitable from a pure business economic point of view.

The total use of recycled paper in Norway is 200-230 000 tons depending on the capacity utilization in the industry. This gives a recycled fibre content in Norwegian produced paper of 10-12%. Most of this is used in packaging papers; in the production of newsprint and magazine papers (which is the most important paper production in Norway totalling 1.5 mill tons per year), no recycled paper is used at present. In 1991, about 189 000 tons of paper was collected in Norway, of which 81 000 tons was exported, mostly for newsprint and printing paper production abroad. At the same time the import of recycled fibre to the country was 46 000 tons, nearly all for packaging papers. The total paper consumption in Norway was in 1990 540 000 tons, of which 300 000 tons was newsprint, magazine and other writing/printing paper, about 200 000 tons was packaging paper, and about 40 000 tons was sanitary and household paper types (Trømborg & Solberg 1995b).

Forestry and the forest industries are one of the most important land-based economic activities in Norway, and the newsprint and magazine paper production is particularly important accounting for about 30 % of the total annual wood harvest in the country. In addition the pulp industry is an important user of chips from the sawmilling industry, effecting significantly the latter's profitability. If increased use of recycled paper takes place (either as a result of regulations based on the environmental arguments mentioned above, or for pure business economic reasons), it might have severe impacts both on the forestry and forest industries of the country. As most of the newsprint and magazine paper is exported to EU, the regulations in EU regarding possible minimum content of recycled paper, is of particular interest.

It was therefore found relevant to make a study of the consequences of increased use of recycled paper in Norway. Four alternatives for the increased use was specified (cf. below) and the consequences regarding timber prices and wood harvest on a regional basis are analysed for each of them. The main purpose of this paper is to present the methodology and results of the study, and discuss the main results. A second purpose is to discuss the weak and strong points of the analysis model used in the study, and suggest main model improvements, if necessary.

Methodology

Model

A regionalized partial equilibrium forest sector model for Norway is used for the analysis. The model, called NTM (Norwegian Trade Model), is based on the same main principles as GTM (Global Trade Model) developed by IIASA and outlined by Kallio, Dykstra & Binkley (1987), and further developed and applied on the Finnish forest sector (Ronnila and Kallio 1992, Ronnila 1995). The Finnish version is modified to cater for special conditions in Norway. NTM is described in detail in Trømborg & Solberg (1995a). It consists of 10 domestic regions and two regions for respectively export and import. 27 products are included in the model, of which there are six roundwood (timber supply) assortments (sawlogs and pulpwood for the three species birch, Norway spruce and Scots pine). In each region there is a timber supply of each of the six roundwood assortments, production of forest industry products, and import, export, and consumption of all the 27 products. One important «link» between the regions is the transport costs, and the objective function is to maximize the net economic surplus of the whole domestic sector, under the given constraints. As shown by Samuelson (1952) this is the same as maximizing the sum of consumers' and producers' surplus for each region and product minus the transport costs, as well as it at the same time gives the market equilibrium solution obtained under conditions of free competition.

As such, NTM finds for each product and region, the equilibrium prices, production, consumption, intermediate use, and trade between the domestic regions, and import/export. In addition the model finds the increase in new capacity for the forest industry products: whenever the total investment and production costs of new plants are lower than the marginal variable costs of the present industry (given by the market price), new investments will take place, with a new technology (i.e. production inputs) specified for each product. The model solution is found for each five-year period and for five periods, starting with the year 1990.

Because the objective function ensures consistent and realistic market equilibrium solutions, NTM is particularly well suited for analysing the consequences of changes in exogenous factors like e.g. changes in the use of recycled paper.

Main assumptions

The following four scenario alternatives regarding increased paper recycling are analysed:

- Alternative 1 «25% in Skogn»: This alternative assumes 25% recycled paper in the newsprint production at Norske Skogindustrier's factory in Skogn, which is the largest newsprint producer in Norway with a capacity of about 500 000 tons per year. This represents an annual use of recycled paper of about 140 000 tons assuming a loss of 10% in the recycling process. This quantity could be collected domestically in Norway, and the alternative would give a recycling rate of 50% of the consumption of newsprint, magazine and other printing paper in Norway.

- Alternative 2 (20% in newsprint): This alternative assumes 20% recycled paper in all domestic produced newsprint in Norway, and corresponds to an annual use of 230 000 tons of recycled paper. This is about the theoretical maximum which could be collected in Norway for this kind of production, and represents a recycling rate of about 75% of the consumption of newsprint, magazine and other printing paper in Norway.

- Alternative 3 (50% in newsprint): This alternative assumes 50% recycled paper in all domestic produced newsprint, corresponding to an annual use of about 570 000 tons of recycled paper at maximum capacity production in Norway. This implies that a considerable quantity of recycled paper has to be imported to Norway.

- Alternative 4 (50% in newsprint and 25% in magazine): This alternative assumes 50% recycled paper in all domestic produced newsprint (i.e. as in alternative 3), and in addition that half of the mechanic pulp for magazine paper production and wood contained printing paper is substituted by recycled paper. This corresponds to Saugbrugsforeningen A/S producing SC-paper with about 25% recycled fiber content (assuming 500 000 tons production at this factory), and A/S Holmen-Hellefos producing book-paper with a recycled content of about 40%. Altogether this alternative assumes about 710 000 tons of recycled paper.

These four alternatives are compared with a base alternative. This alternative is defined in detail in Trømborg & Solberg (1995c), but could in short be described as the most likely development of the forest sector without any «forced» increase of the use of paper recycling as defined above for alternatives 1-4. Thus, the model assumptions in the base alternative are the same as in alternatives 1-4, except for the assumptions on the use of paper recycling. It is also assumed that the production of paper remain the same as is the base-scenario.

Data

The data used in the analysis are described in detail in Solberg & Trømborg (1995b). A modest increase of the general demand of forest products is assumed. Another main assumption is that the price elasticity for imported pulpwood is higher than the domestic pulpwood supply in Norway.

Results

Increased use of recycled fiber gives reduced input of virgin fibre. Regarding the production of newsprint and magazine paper, it is particularly the input of mechanical pulp which is reduced, and the consequences will be highest for the pulpwood price of Norway spruce. As seen from Figure 1 this price, relative to the price in the base scenario, will be reduced by respectively 5%, 7%, 20%, and 25% for the scenario alternatives 1-4 defined above.

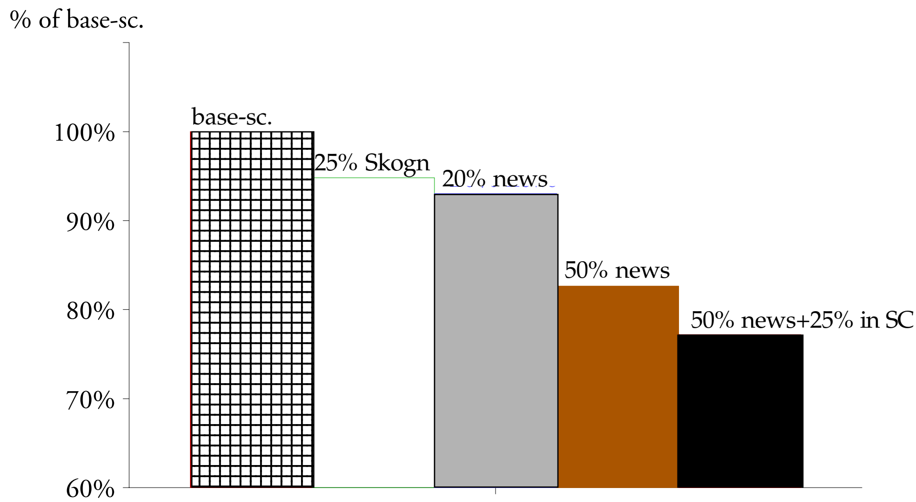

Figure 1. ***Price of spruce pulpwood in Norway by different levels of recycled fibre in newsprint and SC-paper in Norway.***

Figures 2 and 3 show the domestic harvest and the import of spruce pulpwood for the four scenario alternatives. Table 1 gives a comparison of the increase in the use of recycled fibre and corresponding changes in pulpwood prices, harvest level, and import of pulpwood. It is seen that there are rather significant changes.

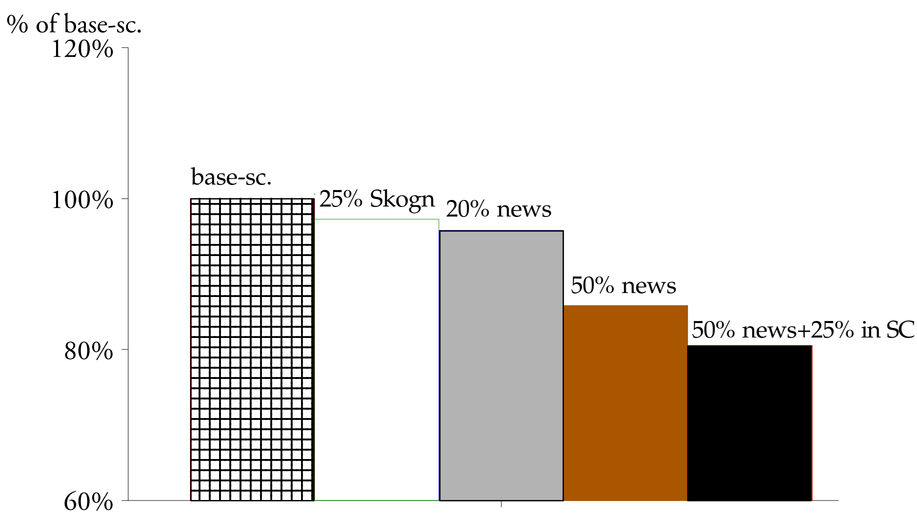

Figure 2. ***Domestic harves of spruce pulpwood in Norway by different levels of recycled fibre in newsprint and SC-paper in Norway.***

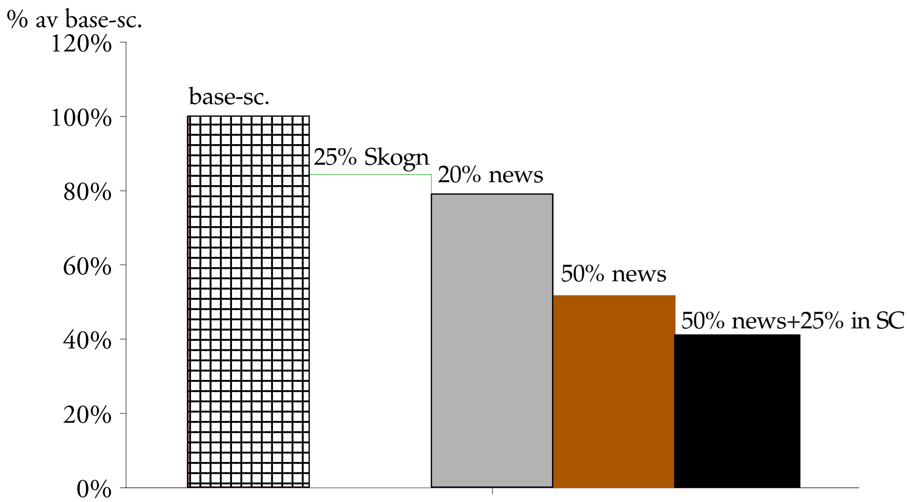

Figure 3. ***Import of spruce pulpwood to Norway by different levels of recycled fibre in newsprint and C-paper in Norway.***

The price fall on spruce pulpwood implies a corresponding fall in the wood chips price which the sawmilling industry obtain from selling to the pulp industry. Under the assumptions mentioned above, scenario alternative 4 will give a reduction in the income of the sawmills corresponding to about 50 NOK per m^3 of sawnwood - i.e. about 3% of the gross sales value in the model. This influences of course the profitability of the sawmills, but lower the sawnwood production only little. It therefore, also, has little influence on the demand for spruce sawlogs.

Table 1. ***Increased use of recycled fibre and corresponding estimated changes in pulpwood used, domestic harvest, and domestic spruce pulpwood price.***

Scenario alternative fibre used	Increase in recycled quantity	Reduced pulpwood harvest	Reduced Reduction domesticpulpwood price	
1	140 000 t	320 000 m^3	80 000 m^3	5%
2	230 000 «	490 000 «	140 000 »	7%
3	570 000 «	1220 000 «	530 000 »	20%
4	710 000 «	1550 000 «	730 000 »	25%

Discussion

Model results

Pressure from the market or governments for increased use of recycled fibre in the newsprint and magazine paper production could give more severe negative implications for the Norwegian forest sector than for the forest sector in most other countries, because at present no recycled fibre is used in this production in Norway. For comparison, Sweden and Finland had in 1993 a recycled fibre content of respectively 17% and 6% in newsprint (Andersen 1993). In addition the population density in Norway is very low, giving high paper collection costs.

If the use of recycled fibre for newsprint and magazine paper increases, the consequences will be reduced forestry income because of reduced timber prices and corresponding reduced harvesting of timber. A reduction of the domestic harvest level of 530-730 000 m3 per year (corresponding to an increase in the use of recycled fibre of about 570- 710 000 tons per year) will today imply an employment reduction in forestry of about 500 man years - i.e. about 5% of the labour input in forestry today (including the increased employment in the transport of recycled paper).

The pulpwood price reduction influences the wood chips prices for the sawmills. Even if the consequences on the sawmill production is not very high, this factor may influence the localisation of the new sawmill investments. In the model, this effect is not shown because it is assumed a rather high free capacity in the present sawmills.

The sawlog supply is in the model not directly influenced by the pulpwood price. In reality, however, a decreased pulpwood price will give lower total net price of a forest stand to the forest owners, all factors equal, and the sawlog supply should decrease. However, the reduction will be counterbalanced by at least two factors: First, that the forest owner will direct his harvest to stands having less pulpwood contents relative to sawlogs, as well as postponing thinnings to get a higher share of sawlogs; secondly, price expectations will most likely also decrease. In short, the assumption in the model of sawlog supply being independent of the pulpwood price might be rather realistic.

Andersen (1993) has analysed the consequences of increasing the use of recycled fibre in the Norwegian newsprint industry to 30% and 50%. He found that the pulpwood price in Norway would be reduced by respectively 15% and 27% in the two alternatives. The main reason for this being higher than our results, is that Andersen op. cit. does not include the possibility of import of pulpwood in the analysis model.

In this analysis we have assumed that the production in the Norwegian pulp and paper industry is the same in all alternatives, including the base scenario. The realism of this assumptions depends upon the costs and profitability of the investments necessary to get the increases in the use of recycled fibre assumed in the four scenario alternatives. This will in Norway depend upon how much of the costs (investments as well as paper collection costs) the industry itself will have to pay, and the world market price of recycled fibre. Both these factors are uncertain at the moment. If the costs are too high for the industry, one consequence could be that the industry will investment more abroad in countries with lower recycled fibre costs.

Model used

In Norway we have experiences with many types of forest sector models - from pure simulation models (Randers 1977, Randers & Lønnstedt 1979) to various kinds of equilibrium models (Gundersen & Solberg 1984, Solberg 1984,1986, Andersen 1993, Trømborg & Solberg 1995a).

Compared to pure simulation models having no optimization algorithms securing economic consistency in each scenario alternative analyzed, equilibrium models have in our opinion rather strong advantages for this kind of analysis. Equilibrium models also follows basic principles of economic theory, which is an advantage in the discussion of validity of assumptions and results.

Compared with the other partial equilibrium models used, it is our opinion that the model applied in this analysis has the following advantages:

- The regional aspect is very well taken care of.
- The forest sector is well described as the forest industries are included at individual plant level.
- The non-linear timber supply equations used is most likely more realistic than the linear supply relationships used in the previous models.
- The algorithm applied is highly efficient, making possible solutions in very short time.

If resources were given to improve the model for making better analysis of the problem tried analysed in this paper, we would have given highest priority to the following factors in priority order:

- Improve the substitution possibilities regarding sawlog and pulpwood supply.
- Make possible non-linear demand functions (the present linear approximation of the demand functions might give too large changes in demand when price changes).
- Make the model more user friendly.

Conclusions

Increased use of recycled fibre in the Norwegian newsprint and magazine paper industry will influence the harvest level and prices of domestic spruce pulpwood significantly when the content of recycled fiber exceeds 25%. The profitability of the sawmill industry will be lowered because of the price decline of chips and residuals. The impact on the profitability of the newsprint and magazine paper industry will depend upon the cost of the recycled fibre.

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LCA IN THE INDUSTRIAL POLICY PERSPECTIVE OF THE EUROPEAN UNION - THE INDUSTRIAL AND ENVIRONMENTAL INTERFACE

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Abstract

The purpose of this paper is to take a look at Life Cycle Analysis (LCA) from a policy-maker's point of view by considering it firstly in a naïve way as a ready-made, expert tool for policy-making, secondly considering the scientific and practical difficulties which are involved in using such a tool and finally to examine the interaction of the tool with the policy-making process itself. Emphasis is placed on the ranges of starting points and disparate potentials for applying LCA which exist throughout the EU member states and the consequent need for compromise in the formulation of EU policy. Finally, some of the possibilities for the use of LCA, as one element in the development of environmental policy and its interface with industrial policy are considered. In this context, the cases of forest and timber certification and possible wood product eco-labelling - for Sustainable Forest Management (SFM), are examined.

The main elements include:
1. LCA as a tool available to research and policy-making, ("cycles and chains"),
2. The limitations to using LCA, the diverse positions of the EU member states,
3. The role and problems of policy-making,
4. An over-view of EU Industrial Policy,
5. Some aspects of EU Environmental Policy, the role of LCA,
6. Challenges facing forestry and the forest-based industries ("filière forêt/bois"),
7. Policy-making in a unique, but diverse sector; eco-certification, eco-labelling,
8. Towards a possible EU forest and timber certification system.

* NB. Whilst the author works for the European Commission (EC), the nature of this workshop means that the views expressed may not necessarily reflect official Commission policy. (NB From 01/07/95 the author works for the new "Wood and Paper Industries Unit", DG III/C/5).

	PLANNING & PREPARATION	SEED COLLECTION NURSERIES	FOREST PLANTING & ESTABLISHMT.	MANAGEMT. MAINTENANCE PROTECTION IMPROVEMENT	HARVESTING & MARKETING	ROUND-WOOD	SAWN GOODS	PANELS	PULPS	PAPER & BOARD	P & B CONVERTING	PRINTING	PUBLISHING	RECYCLING
ACTIVITIES					felling extraction cutting-up de-barking stacking loading marketing etc.	constuct. pilings transmis. fencing fuelwood industrial wood	sawn softwood sawn hardwood veneers parquet sleepers	plywood particle bd eg. OSB fibreboard eg. MDF glulams LVL, LSI blockbds etc.	mechanical chemical - sulphite - sulphate etc. semi-chem thermo-mech ctmp etc.	newsprint other graph. packaging grades hygienic & sanitary other	packaging hygienic office other	gravure offset other	newspapers magazines books others	waste wood waste paper: eg. newsprint OCC wood-free mixed
MATERIAL FLOWS														

Figure 1. Structure of forestry sector (resources and processing industries) - the "forest/wood/paper/graphic chain".

1. *An appraisal of LCA as a tool available to research and policy-making*

Definition: Life Cycle Analysis (LCA) is a tool which might be defined as:

> *"the qualitative and quantitative examination of the material and other inputs, outputs and processes related to a given product throughout its existence."**

The concept of life cycle has its origins in biology, in looking at the renewal patterns of various organisms, i.e. their life histories and reproductive cycles. The word "cycle" assumes a certain sequence of replacement, or "biological recycling", whereby a given organism is sooner or later replaced by its off-spring. However, in the case of industrial and consumer products, such replacement is seldom the case and one might better consider an analogy in which the cycle is broken and formed into a chain, or at least partially broken, with only some elements being "recycled". Typically, an industrial or consumer product will have material, energetic and other inputs and outputs, and the processes it undergoes may result in recycled materials. However, ultimately there will be by-products and inevitably waste products, whose composition at the end of the product's "life" is different from that at the beginning. Thus, one might well use the chain analogy.

In the case of wood, which is itself often described as "renewable", such a chain of events may be found in reference to the material flows which occur throughout the "forest/wood/paper/graphic chain" **. Whilst some authors refer to the "forest cycle" (Remröd, 1993) to describe the way in which sustainable forest management can offer an endless stream of wood and other benefits, the concept of a cycle is in fact only fulfilled if indeed the very broadest interpretation is considered over a very long time period. In contrast, the effective "life span" of a consumer product is typically much shorter and thus the various segments of the overall "life cycle" are often only linked in their immediate sequence and a cycle is thus seldom completed. An attempt to depict the forest/wood/paper/graphic chain is shown in Figure 1, with a simplified version in Figure 2.

2. *The limitations to using LCA, the variable position of the EU member states*

Whilst LCA may be considered as a scientific tool, based on all the worthy principles of the scientific method and using quantitative information to the maximum, it is nonetheless an imperfect one since seldom will all such necessary or desirable information be available. The uses of Life Cycle Analysis in research and policy-making may differ considerably according to the breadth of vision under

* NB there is no widely-accepted "official" definition; however, for OECD's see OECD, 1995.

**A more concise term for this chain is found in the French "filière forêt/bois".

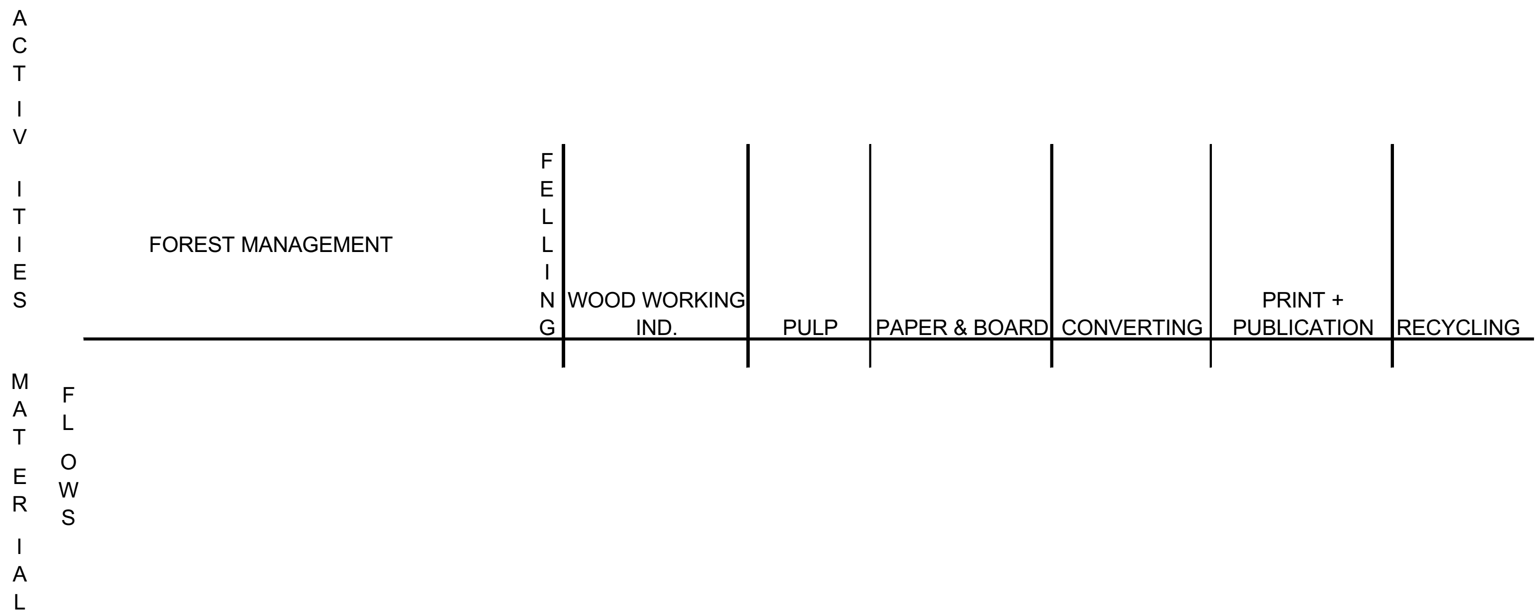


Figure 2. ***The forest/wood/paper/graphic chain (cycle?).***

consideration. For instance, determining energetic inputs into the making of wood panels may be a discrete area of research for the manufacturer, whereby all inputs and outputs can be closely monitored in closed conditions and over a relatively short time period and hence the (energetic) LCA be relatively complete, accurate and reliable.

In contrast, to ascertain for policy-making purposes (e.g. the formulation of an environmental award) which wood panels have the best environmental bill of health is much more problematic. Emissions from bonding agents may (or may not!) be measured reliably. However, as to whether or not the wood going to the panel-making process has come from a sustainably-managed forest may remain a more open question, even if all available LCAs have been carried out. For instance, the LCA for sustainable forest management (SFM) may only be able to look at certain parameters, such as soil conservation, water run-off, growing stock volume and so on. Time series data may be partial or non-existent. Bio-diversity measures may vary through time with the dynamics of the forest eco-system itself and thus what may inevitably be short-term samples will not give a true reflection of the overall "life cycle" of the forest. This is without even addressing the issue as to what constitutes sustainability and in policy-making - as in the commercial world - definitions may vary considerably.

The integral consideration of the time element in using LCAs is often referred to as the "cradle-to-grave" approach, the inference being that LCAs should consider every input and output related to a product from its "birth" to its ultimate "death". Notwithstanding the enormous difficulties in determining the precise moments at which a product's birth and death occur, the use of LCAs on renewable materials and products such as wood, automatically begs questions about "parentage" (if not pedigree) and "successors". In other words how far upstream and downstream of the wooden consumer product itself should and/or can the LCA go. Furthermore, in practice and beyond the situation wherein not all information desired is available, there may be cases, particularly in the realms of policy-making, where LCAs may only be used partially, or even where they are used selectively to suit a particular purpose.

Beyond these scientific and other considerations remains the fact that for policy-making purposes within the EU there is a wide rage of situations between and even within the diverse member states, firstly as to whether LCAs can be performed, secondly as to whether they can be performed completely and comparatively and thirdly whether they can be used coherently across the Union.

This fact does not necessarily reflect different states of scientific or other development between the various EU members, but rather, and particularly in reference to forests, forest product markets and processing conditions, the heterogeneity of the Union. For example forest inventory may only look at wood volumes in one country, whereas bio-diversity and aesthetic considerations may be high on the list of priorities elsewhere. Use of water may not be given a second thought in some regions, whereas in others it may be a limiting factor to tree growth.

Beyond these physical constraints, administrative and legal structures vary as well, so that all-in-all, the policy-maker may be obliged to take a LCD (lowest common denominator) approach to LCA.

Overall, then LCAs may at best be seen as only semi-scientific tools at the disposal of the policy-maker.

3. The role and problems of policy-making

Definition: Policy-making might be defined as:

> *"To devise means (statutory/recommendations/voluntary) for maintaining or changing a system in a given field of human activity (economic, cultural, social or other) so as to achieve a desired result".*

Policy-making is an inexact business, a process combining knowledge with judgement. It is often fraut with pitfalls throughout its many stages and in democratic systems necessary compromise can sometimes lead to unworkable fudges and/or administrative nightmares. Its essential elements are as follows, irrespective of whether the results be successful or not:

i) **Awareness** - of the background situation which gives rise to the need for policy-making (status quo), together with the pressures which may exist for change, together with "background knowledge", i.e. intelligence about the situation and/or the actors involved,

ii) **Information** - this may be scientific, e.g. the results of scientific and economic research and development, or semi-scientific e.g. consultancies, opinion polls, consumer surveys etc.,

iii) **Opinions and Advice** - semi- and non-scientific information, often in the form of counselling from:

- other policy-makers (past and present), including political input,
- advisory bodies (committees, etc.),
- consultants and others (including individuals),

iv) **Assessment** - logical analysis and re-synthesis of 1-3, above,

v) **Judgement** - the application of subjective personal skills to 1-4, above,

vi) **Luck** - the intervention of chance events, either positively or negatively,

vii) **Conclusions** - the resultant output of the above steps.

The extent to which these different elements interact is very variable, with sometimes a relatively balanced input from each of them, at other times one factor may dominate, such as luck, political input or judgement. Before considering how the factors interact in the case of LCA, some words about EU Industrial Policy and its links with the environment.

4. *An over-view of EU Industrial Policy*

The backcloth to the development of the EU's Industrial Policy is formed from the chronic challenges facing our industry in general, in particular:

- persistent and high unemployment,
- increasingly sharp international competitiveness,
- rapidly spreading new technologies,
- changing market and geopolitical structures, and
- displacement of industry from its traditional locations.

In its recent White Paper on Industrial Competitiveness, the European Commission laid the foundations of an EU Industrial Policy (COM (94) 319) to confront these challenges, based on the following four pillars:

1. The **promotion of intangible investment**, including training and research, and the promotion of information and dialogue,
2. **Industrial Cooperation**, both within and outwith the EU,
3. The **development of competitiveness**, both internationally and internally,
4. The **modernisation of the role of public authorities**.

Whilst the fourth of these elements is arguably less important for the relatively unregulated EU forest-based industries than are 1-3, we can examine how the other three elements are put into practice in this sector.

4.1. Promotion of intangible investment

Regarding the promotion of intangible investment, we can see that there is a firm recognition of the industry's needs in various training and re-training programmes, often under the Structural Funds (Agricultural, Regional and Social Funds) as well as under the Fourth Framework Programme for Research and Development. This latter contains a sectorial programme of research, development and demonstration on agriculture and fisheries, including :

- agro-industry,
- food technologies,
- silviculture,
- aquaculture, and
- rural development.

Together, the agro-industrial, silviculture and rural development elements of this sectorial programme, provide research, development and demonstration opportunities at the EU level for the ensemble of forestry and forest-based industries.

Within this sectorial programme, the research areas:
- integrated production and processing chains,
- scaling-up and processing methodologies, and
- agriculture, forestry and rural development

are of interest to those in the industry. (It is curious to note that processing chains are mentioned rather than cycles!).

Furthermore, some elements of the sectorial programme on Non-Nuclear Energy may also bear an examination by those in the industry.

Finally the ESPRIT programme on the application of Information Technology offers a host of opportunities to all sectors, not least the forest-based industries.

4.2. Industrial Cooperation

The **objectives** of industrial cooperation are to
- improve the presence of EU industry in high-growth markets,
- better understand the industrial situation of the EU's trading partners,
- encourage private cooperation schemes of EU interest,
- facilitate transfers of experience and know-how between businesses, especially Small- and Medium-size Enterprises (SMEs).

These objectives are approached on two fronts: **internally** to the EU and **externally**, with the following examples:

- **Internally through**:
  - **Industrial Round Tables**, focusing on sectorial interests. (Such events have often included or been addressed to the pulp, paper and board industries),
  - the **identification and removal of legal and fiscal barriers** to industrial cooperation, such as the further refinement of **Merger Control Policy**. This has had, and will continue to have an important role in the forest industries' sector, particularly for pulp and paper,
  - the **Working Party of the Heads of Industrial Policy Departments**, which includes representatives from the paper industry,
  - restructuring of the **"Filière Bois" or "Wood-chain" Committee** to reflect both the evolved market situation and the new **enlargement**, which above all **doubles the EU's forest resources and more than doubles its forest industry capacity**.

- **Externally**:

through cooperation with other geopolitical areas such as the **CEECs**. (Central and Eastern European Countries), the **CIS** (Commonwealth of Independent States), the **Mediterranean** countries (now leading to a Mediterranean Policy)and with **Latin**

America and **Asia** (sometimes known as the "**ALA**" countries). In particular the **APEC** summit has underlined the importance of the latter.

In Central and Eastern Europe, cooperation with an increasing number of the **CEECs** is fostered through the **Europe Agreements** which have allowed free trade within 5 years from 01/01/95. In addition to these are various events such as:

- the **Baltic States/EU Industrial Round Table** of May 1994, which had forest industries as one of four priorities,
- the **EC/CITPA Study Tour to the Kaliningrad Oblast**, June 1994
- **East/West Seminars** on the both the **Woodworking Industries** and the **Paper, Converting and Graphic Industries**, during 1995,

Further afield, 1994 saw the re-birth of the **EU/Canada Working Group on Forest Products**, under the **EU/Canada Sub-Committee on Industrial Cooperation** and new contacts with the **A.T.T.C.** (Asean Timber Technology Centre) in Kuala Lumpur, as part of the **EU/ASEAN Cooperation Programme**.

4.3. *The promotion of competitiveness*

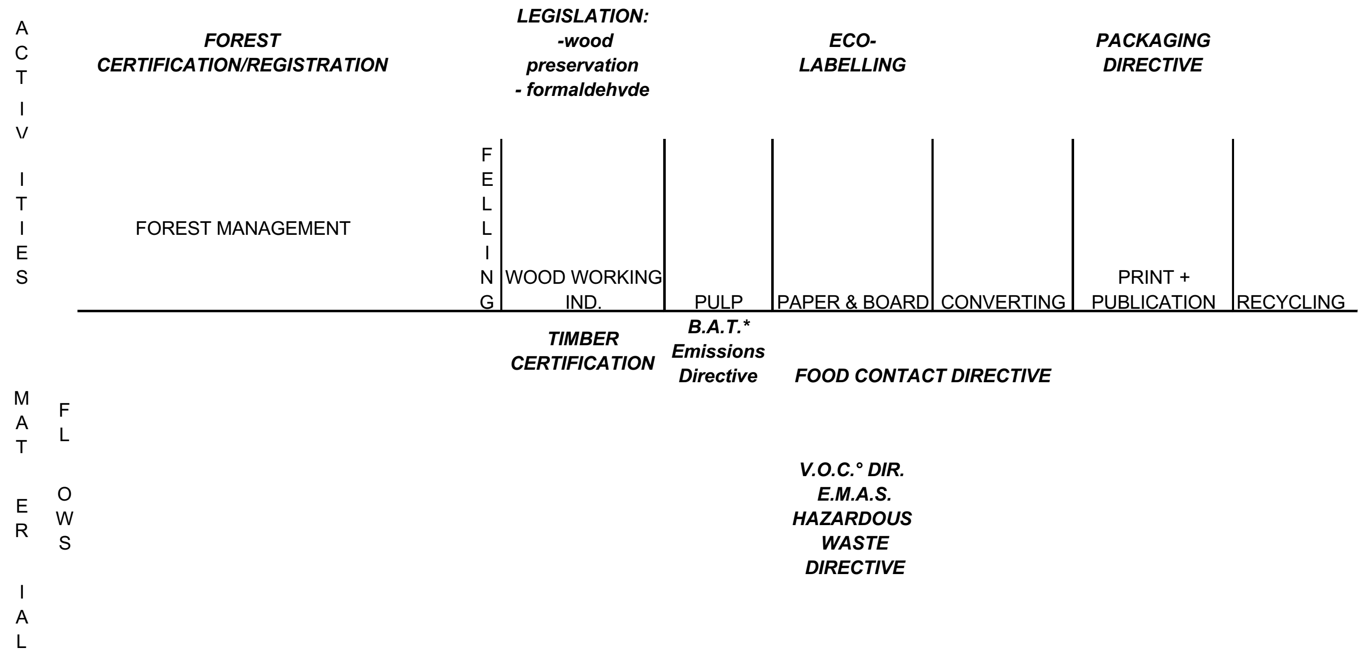
Again, the EU's approach is two-fold:

- **internationally**, cooperation is encouraged through:
  - the development of international competition rules,
  - the elimination of non-tariff barriers,
  - the establishment of the WTO (World Trade Organisation),
- **internally** through:
  - reinforced rigour in the control of state aids,
  - making this control more horizontal (i.e. non sectorial) as well as transparent.
  - improving coherence between the various EU policies, such as regional, industrial and competition policy,
  - assuring a balance between competition and cooperation in both the internal and external relations of the EU.

Given the diverse and complex nature of the above issues it is not intended to go into them in depth in this paper, however they do comprise a significant part of the workload in the application of EU Industrial Policy to the Forest-based Industries.

5. *Some aspects of EU Environment Policy*

Whilst EU Environmental Policy has an all-embracing nature, capable of addressing any issue of concern in the environmental field, its application so far could be regarded by some as piece-meal. This could be the case as far as the forest-based



* B.A.T. = Best Available Technology
° V.O.C. = Volatile Organic Compounds

Figure 3. The forest/wood/paper/graphic chain (cycle?).

industries are concerned since for them it is arguable that not all issues facing the forest/wood/paper/graphic chain are treated, at least not with a constant intensity. Hence EU initiatives, especially legislation could be seen as *ad hoc*. Figure 3 (in which various environmental initiatives are overlayed onto Figure 2, the forest/wood/paper/graphic chain) attempts to visualise this. Some of the instruments of Environmental Policy are discussed below and it can be seen that whilst one might apply an LCA to a given forest product during its passage along the forest/wood/paper/graphic chain, the policy elements do not necessarily form such a linked sequence. Some elements incorporate LCA in their own internal processes, but this fact is not necessarily mirrored by other policy elements.

Understandably partial solutions may be imperfect and their decisions slow in the making. Thus for waste management, the **EU Packaging Directive** (Directive 94/308/EC), which was only agreed after years of consultations, may only "smooth out the bumps" rather than bring the uniformity of a level playing field between the member states, since its flexible nature and the greater financial means of some member states vis-à-vis others, will inevitably mean that disparities will persist. As with LCA itself, there is a range of starting points between the member states from which they begin to apply the Directive and thus totally uniform conditions cannot be assured throughout the Union in the first instance. After time, however, the disparities should become less obvious.

Since the publication of the **EU Eco-label** framework Regulation in March 1992 (Council Regulation 880/92), the development of individual Decisions for given product groups has continued, but progress has been rather disappointing, not least in the case of paper products. Part of the reason for this stems from the fact that there has been opposition to the technical details of the proposals from various interest groupings, whether industrial, environmental or consumer-oriented. However, it must also be said that there have been problems for all concerned from the conceptual point of view, one important issue being whether a given proposal deals more with the product and the environmental impacts of its use than with the processes included in its manufacture.

According to the framework of the Eco-label Regulation, a proposal for an individual Commission Decision for a given product group is made following an LCA study. But not everyone agrees where the life cycle should begin and where it should end, still less which elements should be prioritised from an environmental view-point. For instance, how far back up the forest/wood/paper/graphic chain should one look for the "birth" of paper in the form of wood fibres? For virgin fibres this could be in the wood-yard of a pulp mill, at the forest gate or out in the forest itself? If the latter is the answer a further question then arises, "what is sustainability in terms of forest management?" Definitions vary almost as much as view-points, although there is a growing consensus that the "Helsinki" definition should be used at EU level, at least for the foreseeable future. Alternatively, if recycled fibres are considered, when does their "birth" take place? Should their energy requirements and emissions be counted several times? Not to mention which emissions could/should be measured and for which should greater environmental weight be given.

The case of eco-label, at least in the EU context, has been a classic example of using LCAs, but also realising their limits as one tool amongst others. The ultimate need for compromise with more subjective considerations has become evident in the policy-making process. It is clear that an eco-label is at the very least an information tool for communicating certain aspects of a product's environmental impact to consumers of that product and indeed to the public at large. However, what is less clear is the extent to which an eco-label should be used as a marketing tool by manufacturers and distributors of the product to gain market share over their rivals. Clearly some eco-labels are used in this way, even though this purely commercial exploitation may not have been on the minds of the policy-makers when the schemes were devised.

So far there has been no proposal on an **Eco-tax** at the European level, however, and arguably in keeping with the commitments all EU member states gave at the Rio Conference on Environment and Development, the possibility of a tax on unsustainably produced wood has been hinted at, notably by the former Environment Commissioner, Mr. Paleokrassas. There have nonetheless been some national eco-tax initiatives, firstly from Belgium and more recently from Luxembourg. Up to now these proposals have only been in the form of framework legislation, seeking to impose punitive taxes on products deemed to have high environmental impact.

The products chosen include inter alia disposable razors and cameras, which are felt to be wasteful of raw materials, as well as certain papers which do not contain a minimum of 40% of recycled fibres. For paper in the Belgian and Luxembourg examples an eco-tax level of 10 BF/kg (10,000 BF or c. 263 ECU/tonne) has been suggested, in which case manufacturers would not only risk losing their profit margins, but their market share. Moreover, the precedent of a minimum recycled fibre content in a given product would be a first on this side of the Atlantic, whereas more generally in Europe, and notably at EU level, the principle is being established that virgin and recycled fibres can be equally valid and complementary resources, rather than foes, so long as the former come from SFM systems. Indeed, recycled fibres depend for their origin on a constant input of fresh fibres into the paper chain.

However, it is not clear to what extent LCAs have been used in the selection of the product groups concerned, or in the calculation of the eco-tax to be applied. One important consideration would be the use of LCAs in a quantitative way, for example to establish to what degree different product groups or indeed individual products could/should be taxed. Another vital issue is whether or not the revenues raised from such eco-taxes are used to environmental advantage. Do they go directly to reduce the environmental impact of the products concerned, or to enhance environmental performance in other areas, or are they lost in global budgets? It might be reasonable to assume that revenues from taxes targeted specifically on environmental criteria should be directed back to help solve the problems which gave rise to them, or at least to produce some other environmental benefit.

Whether other environmentally oriented taxes become established in other ways in the future remains to be seen. In the context of the (rightful) concern about Global Warming, there has been much discussion the world over of **energy taxes and/or CO_2/C_4 taxes**. The latter have been proposed, though at very modest rates in North America, where energy costs are generally much lower than for their European counterparts. However, industry, irrespective of the specific sector involved, has been very resistant towards taxation of the use of energy as an indicator of CO_2 build-up in the atmosphere. This is largely through concern about increased energy costs contributing to lower industrial competitiveness, although everyone seems to agree that if everybody applied an energy tax in the same way then no-one would be any less competitive than he would otherwise be. However, aside from the leadership issue of "who goes first?", the determination of an equitable, scientifically-based energy/CO_2 tax remains an open issue. Perhaps LCA is one of the tools which could help to solve this problem in the years to come, and perhaps more significantly also to address the efficient use of energy, irrespective of its source.

As far as **EU Energy policy** is concerned, an important principle has been established in that the Working Group on CO_2 Tax proposed that **renewable** energy sources be exempt any possible carbon tax. This should be good news for the forest-based industries. The pulp, paper and board industries in particular consume vast amounts of energy in manufacturing, but, based as they are to a large extent on renewable materials, a large portion is used for energy generation, they should. derive advantage from such an exemption if any such energy or carbon tax did come into being.

The initiatives commented on above are examples of sporadic intervention along the forest/wood/paper/graphic chain. Perhaps, as these are complemented by others and all of them refined to fit better with each other, we will ultimately see an integral approach to environmental matters affecting the forest-based industries and indeed, industry in general. Some opponents of the EU Eco-label scheme outlined above, see **Environmental Management and Audit Systems** or E.M.AS, as it is more popularly called, as this type of approach. At EU level, the legislation for an EMAS initiative, in this case a Community **eco-management and audit scheme** (Council Regulation (EEC) No. 1836/93), may be seen as complementary to some other, more specific environmental policy instruments, such as eco-label, rather than an alternative. EMAS offers a broad framework for environmental improvement which is monitored and up-graded, so that irrespective of their starting points, all companies in a given industry can improve their performance in a relative way.

However, it should be remembered that EMAS is site-specific in its application and its monitoring, reporting and auditing are concerned with all activities by a company at a given site, in other words all the processes which take place there as opposed to merely the industrial product manufactured and its own environmental impacts. If more than one product is manufactured the whole set of environmental implications are taken into account. Thus, EMAS could embrace processes which are not directly related to the product or its performance, whereas eco-label can deal with these.

Nonetheless, this fact does not obviate the need for absolute improvement and some scope for its recognition. Furthermore, since the EU EMAS scheme is something in which companies can participate at an individual level, there is still space for industry as a whole, or perhaps certain identifiable sectors such as the forest-based industries to reinforce its effects with some kind of concerted action. Even if the latter is not possible EMAS should not be used as a mere slogan against eco-label, or indeed as a fig-leaf for hiding a lack of action. So far, such a coordinated action from amongst the EU's forest-based industries has not been obvious.

6. *Challenges facing forestry and the forest-based industries ("filière forêt/bois")*

The European forest-based industries, in which can be included all elements of the forest/wood/paper/graphic chain face many challenges, both within the EU and increasingly in the wider European context. Physical threats such as fire, forest decline (so-called "acid rain"), windblown, insect pests and drought are all well documented, as indeed are the increasing calls for changes in forestry policy the public at large, and more vociferously from various factions of what many in industry call simply, "the environmental movement". However, there are still other handicaps facing the "filière forêt/bois", as the French put it so eloquently! Not all of these challenges are obvious. For instance, it may seem comforting to learn that, since the recent enlargement of the EU to include Austria, Finland and Sweden, our forest area has doubled, our pulp capacity has tripled and our paper capacity has increased by 50 % - to make us a net exporter of the latter product! Nonetheless, both our forest resources and downstream processing industries are handicapped in the competitive sense.

To begin with, the EU has very little of the world's forest resources, although on a pro rata basis a higher than average percentage is exploitable, and indeed on average per hectare wood removals are higher in Europe than in North America or the former USSR. However, notwithstanding that much of Europe's forest area, particularly that in mountain zones, consists of protection forest, much of the rest is fragmented, if not physically, then at least in terms of ownership. Estimates vary across the Union as to the number of private owners, who collectively account for over half the surface under forest. There are at least five million and probably many more. Accordingly, the average area of forest holdings is small, but varies between member states. In Greece holdings are so small that the measurement used is the **stremma**, which is one tenth of a hectare.

European forests are often on land residual from agriculture, frequently meaning that which it has been too steep to plough. Slope compounds timber working costs which are already high due to the poor structure and consequently dense infra-structures such as roads, drains and fire precautions. Transport costs are higher than those in competing regions, largely due to the smaller dimensions of lorries which are allowed in the EU. Raw material costs for both wood and other materials are typically higher as well. Labour costs are higher in Europe throughout the forest/wood/paper/graphic chain, although this is not always reflected in higher wages since productivity can be very variable.

Energy costs in Europe, whether from domestic or imported coal, oil, gas or nuclear processes compare unfavourably with other regions of the world which are important producers and/or exporters of forest products. Add to this the generally very high environmental requirements, whether for forest management or emissions from the industrial processes, and it is easy to see why Europe may be described - in politically correct speak - as "competitively challenged". To be fair, there is a bright side, since the above remarks do not take into account such factors as the high quality of the forest industry workforce, European innovation and a concentration on specialised products having high added value like furniture and fine, printing and writing papers, rather than expensive commodities.

The challenges to the European forest-based industries from the environment, as well as from structural handicaps, globalisation and technology changes are vast, but they are not insurmountable. Scientifically-based LCA is but one tool in the chest with which to face these challenges.

7. *Policy-making in a unique, but diverse sector; eco-certification, eco-labelling*

Many sectors of economic activity may like to consider themselves as unique and indeed, some are in their own way, for instance Agriculture, which has a close relationship with the natural environment - hopefully in a sustainable way! What makes the forest/wood/paper/graphic chain both unique and remarkable, however, is not only the renewable nature of the main raw material, wood, but moreover the long time-scale over which it is produced, even in so-called short rotation forestry (SRF). As discussed earlier, this last aspect renders the use of LCAs for policy-making partial, if not downright problematic.

Nowhere is this more true than in the context of trying to assure sustainability in forest management, or at least in re-assuring consumers of forest products that their production has come about from sustainably grown wood and through processes having a low environmental impact. Proof of such origins is increasingly sought through some form of "certification", as a type of communication tool to the various consumers throughout the different links in the forest/wood/paper/

graphic chain. However, the word "certification" is used to cover a plethora of meanings by different interested parties, who in the jargon of this topic are often referred to as "stakeholders". Before even addressing the environmental issues, there is an urgent need to clarify and hopefully standardise terminology.

To begin with "stakeholder" is not an accurate description of what is most often meant - or at least conveyed - by those who employ the term. Whilst one need not cling narrowly to the dictionary definition of, "one who holds the bets of competing parties during a horse race" (!), the term does have a financial implication, i.e. one who has a stake in something, or more crudely, "a piece of the action"! It is thus respectfully suggested that the more mundane, but more accurate term, "interested party", be used instead.

Coming now to "certification" itself, this word covers a multitude of sins in what one may loosely refer to as the: *"forest certification / timber certification / timber product eco-labelling" continuum*.

Since there is not yet any clearly agreed internationally acceptable understanding as to how terminology should be used, a humble attempt to clarify different aspects is offered here:

a) **Forest certification (registration?)** = the process by which defined areas of forest are recorded (registered) as having some particular identity and/or technical property. The latter may include being subject to sustainable forest management, however defined.
b) **Timber certification** = the process by which any given piece or batch of harvested wood is ascribed a certain characteristic or property. The latter may include provenance, i.e. where it is from, and/or whether it derives from a sustainably managed forest.
c) **Tracing** = the process, or series of steps, whereby a given piece or batch of timber can be monitored from its point of origin from a felled tree through its transport, processing, marketing and ultimate consumption, often via intermediate stages. (This may involve "log labels"!).
d) **Eco-labelling** = the process of ascribing consumer information to a piece of timber or a product derived from it, so as to denote one or more of the following characteristics:
   i) its scientific and/or common name, irrespective of its sustainability,
   ii) its geographic origin e.g. by continent/country/region/forest or concession, irrespective of its "sustainability",
   iii) its origin from a managed forest, again irrespective of its "sustainability",
   iv) its origin from a sustainably managed forest,
   v) the environmental impact of its production processes,
   vi) the environmental impact of its use, etc.

In addition to these general "type" definitions, it may be useful in practice to divide the "certification continuum" up into the following elements:

i) eco-certification of forests (for sustainable management),
ii) eco-certification of wood as a (renewable) industrial raw material (coming from sustainably managed forests)*,
iii) eco-certification/eco-labelling of semi-processed wood products (e.g. sawnwood, panels, structural composites, etc.),
iv) eco-certification/eco-labelling of processed consumer goods which may contain *inter alia* wood.

Beyond the important matter of the correct use of terminology, which is itself essential to an accurate and useful application of LCAs to policy-making, the characteristics of any "certification" system, should surely fulfil a number of basic criteria. Regardless if such a system be devised at the EU, national or international level, these criteria might well include those shown below.

Basic principles for an initiative in forest and/or timber "certification":

i Any such scheme should result in a **traceable environmental benefit**.
ii **No discrimination** should be made between timbers solely on the basis of their different geographical origins, so long as they are comparable as to their end use. In keeping with the Rio Agenda 21, **all tropical, temperate and boreal timber should be treated equally**.
iii It should be based on **internationally agreed principles**.
iv It should be implemented by **recognised and respected authorities** which are credible to all interested parties and which can guarantee **efficient and transparent** operation of the scheme.
v Any **price differentials for "certified"** timber should **only reflect the extra costs visibly associated with sustainable forestry practices** and/or incurred in **administering** the scheme. Any such scheme should in any case be of low cost.
vi There should be **no infringement of the sovereignty** of wood-producing countries. Within the EU the **Subsidiarity Principle** could apply, especially to forest policy.
vii A **realistic time-frame** for the implementation of whatever scheme is most effective in achieving the desired goal of sustainable forestry, so as to give time to producers to alter production technology and governments to create regulatory bodies.
viii A scheme should preferably be **voluntary** in nature, with regulatory steps only being taken if voluntary ones prove ineffective.
ix Any such scheme, which can in any case only reinforce existing sustainable management practices, should be **complementary to other measures** which seek to actively discourage unsustainable forest management (the **"stick and carrot"** approach).

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* Warning: any wood coming from a newly disturbed virgin forest cannot be guaranteed as coming from a sustainable management system until such time as that forest is regenerating in a sustainable way, however defined. In any case, that new forest will be different from its antecedent. LCA will have a vital role in this context.

In contrast to these ideals, the ad hoc certification and eco-labelling initiatives which are presently available represent diverse systems, with limited answerability, variable standards, and an incoherent application, for the timber products covered. This situation can lead to inconsistent practices, a lack of control and an absence of transparency in the pricing of products. Furthermore, a lack of global coordination makes the circumvention or abuse of ad hoc schemes easier, whilst dissipating the impact of consumer choice in promoting sustainability. For instance, a dual market created by the existence of "sustainable" and "unsustainable" wood could foster the risk of abuse by the unscrupulous for product and price differentiation - of the same wood!

As regards the opportunities for *bona fide* price differentiation, it must be clearly discerned to what extent given products and markets are susceptible to price mark-ups. For instance, a distinction must be made between the domestic consumer (D-I-Y) with a willingness to pay an "eco-premium" for small volumes and the construction industry, which, in order to be competitive, needs to bulk-buy at the lowest cost. It is questionable how much of a premium arising from an eco-labelling scheme the latter would be willing and able to absorb.

There is also the risk that a wrongly targeted certification or eco-labelling scheme might be used as a means to ban particular sources of production. Such a proposal could be damaging to the relationship between the EU and wood-exporting countries, particularly LDCs (Less Developed Countries), without addressing the primary goal of sustainable forestry. Such action is illegal under GATT rules and in any case questionable as to its success in promoting sustainability. However, while recognising the objective of the G.S.P. (Generalised System of Preferences) to promote LDCs' economic development, the positive recognition of those producers who meet Agenda 21 could be harnessed through a reinforced form of control, withholding the preferential treatment from those producers who fail to meet certain environmental criteria. Such a system would give incentives to wood-producers and governments alike to implement sound environmental policy, and would recognise the positive steps already taken by responsible elements of the industry in certification programmes.

8. Towards a possible EU forest and timber certification system

Apart from varying definitions of **Sustainability**, although that used in the "Helsinki" process could well serve at EU level there are limitations to extent to which the existing EU Eco-labelling Regulation could provide a sound basis for a scheme for the certification of timber from sustainably-managed forests. These include:

i) The regulation defines product groups by their use, not their origin. This would lead to problems of comparative study. For instance, in such a grouping, tropical timber for window frames could be classed with temperate timber as well as synthetic products, such as metal and plastics, since they are all used for the same kind of product. These have obvious differences in their production and life cycles. For example, some are bio-degradable, whilst others are not.

ii) In this context the present EU definition of eco-labelling focuses on the production process and life cycle of the product. Consequently, it is arguably inappropriate for the natural and renewable resources such as timber. In consideration of the forestry sector, it is not the focus on the harvesting and utilisation of timber, which encourages sustainability, but the utilisation of the land resource after felling. The direct production processes of both sustainably produced and non-sustainably produced timbers are often the same. It is rather the environmental fate of the land **after wood has been taken away** that is the determinant factor. Thus, from a given area of virgin tropical forest, a sustainable future production can be achieved in plantation forestry, agriculture or horticulture, but none of them **sustains** the natural forest. Conversely, land used for building is clearly not contributing to sustainability. However, wood from both the plantation forest and the building site could yield the same results as regards their respective assessment matrices.

iii) A further consideration is that the present eco-labelling regulation applied to timber could be discriminatory against SMEs, owing to the increase in production costs provoked by both registration and operation of such a scheme. These costs could be significant and constitute a burden to SMEs, whereas only larger firms might have the necessary resources.

Regardless of what precise form any EU "certification" scheme for timber might eventually take, there are a small number of options as to a choice in principle. Here is one idea on such options.

1) **An "International-only" initiative**, whereby there would be no specific action in this field by the EU or its member states. One would wait for any possible initiatives which might stem from the CSD process and its follow-up. This may or may not be in conjunction with the development of possible ISO standards on certification/labelling (e.g. ISO 14 000).

   Comment: This process would inevitably take much time, probably several years at least, and there could be further fragmentation at international level in the meantime, and/or a possible clash between governments and self-appointed agencies.

2) **EU/CEN**: Possibly with a mandate from the EU member states, CEN (Comité Européen de Normalisation) could develop standards for a Europe-wide system of certification and/or labelling which could be applied by all the member states.

   Comment: This would take some time, at least 1-2 years, similarly leading to fragmentation in the meantime. There would also be a cost element.

3) **"EU only" initiative**: A correctly-formulated instrument, could incorporate internationally-agreed principles (Rio) and those at European level (H3) into a common, but flexible framework which could include the criteria and indicators being developed as follow-up to H3 within existing national structures of policy and administration. This could respect the Subsidiarity principle, without calling into question the role of the national forest authorities. The various forest industry 'agents' should ideally be involved, but a legal framework could ensure both national government and EU 'control'.

   Comment: This approach could apply to both domestically-produced EU timber and that imported. It could be adopted relatively rapidly, and could be revised to account for further international developments such as CSD follow-up.

4) **National (i.e. MS-only) initiatives**: These would depend on the various options available at national level.

   Comment: The great risk is incoherence and even trade conflicts both on an intra-EU basis and internationally.

Any possible EU scheme should aim to be comprehensive in covering not only the certification of forests, but also the tracing of wood and its certification in the market place for industrial raw materials as well as the eco-labelling of timber products so as to provide their ultimate consumer with information about the environmental impact of its procuration. Without such an approach, the initial step in the chain of forest certification might be of little value if it were not ultimately linked to information being given to the consumer so that he may make his choice of purchase, based on a valued assessment of its environmental implications. Will for instance the paper industry be the first to have sustainably produced and eco-labelled wood from certified forests transformed under the most environmentally-friendly production conditions, obeying all the rules of the closed-loop and energy efficiency, into an eco-labelled product which meets total quality standards and satisfies customer needs, before it is itself recovered and recycled or used for energy ?

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APPENDIX 1

International Workshop

Life Cycle Analysis(LCA) - a Challenge for Forestry and Forest Industry

Time:	3-5 May 1995
Place:	Federal Research Center of Forestry and Forest Products, Hamburg
Organizers:	Federal Research Center of Forestry and Forest Products, European Forest Institute, University of Hamburg

Programme

Wednesday, 3 May 1995

10.00	Opening of the workshop *Prof.Dr. C. Thoroe, Director, Federal Research Center of Forestry and Forest Products* *Prof. Dr. D. Noack, Dean of the Faculty of Biology, Hamburg University* *Prof. Dr. B. Solberg, Director, European Forest Institute, Joensuu, Finland*
10.30	LCA - a challenge for forestry and forest products industry *Prof. Dr. A. Frühwald, University of Hamburg, Germany*
11.00	LCA in forestry *Prof.Dr. Carsten Thoroe, Federal Research Center of Forestry and Forest Products, Germany*
11.30	LCA for wood products *Dr. Klaus Richter, Swiss Federal Laboratories for Materials Testing and Research (EMPA), Switzerland*
12.00	Lunch break
13.00	LCA for pulp and paper products - an overview of economic and ecological consequences of increased paper recycling *Prof. Dr. Sten Nilsson, IIASA*
13.30	LCA in the industrial policy perspective of the European Union *Jeremy Wall, European Commission, DG III*
14.00	LCA in the context of forestry eco-labelling *Christopher Upton, SGS, United Kingdom*
14.30	Coffee break

14.50 Assessing the relative ecological carrying impacts of resource extraction
Wayne Trusty, FORINTEK Canada Corp., Canada

15.20 Building materials in the context of sustainable development: an overview of FORINTEK's research programme model
Jamie Meil, FORINTEK Canada Corp., Canada

15.50 Disposal of CCA treated wood waste by combustion
Antti Nurmi, VTT Building Technology, Wood Technology, Finland

16.20 The strength of the links: an integral approach of the Dutch woodchain
Johan Stolp, Institute for Forest and Forest Products, The Netherlands

16.50 Coffee break

17.10 Forests and forest products: the opportunity for a better CO_2 balance
Richard Sikkema, Institute for Forest and Forest Products, The Netherlands

17.40 Environmental declaration of Nordic wood products
Tore Opdal, The Norwegian Institute of Wood Technology, Norway

18.10 The STFI LCA-database on Swedish forest products
Anne Marie Vass, STFI, Sweden

18.40 The environmental load of fossil fuels in Swedish forestry - inventory for LCA (in production)
Dr. Staffan Berg, Skogforsk, Sweden

19.30 Reception

Thursday, 4 May 1995

8.30 Eco-balancies in the pulp industry: assessment of environmental impacts
Dr. Gerhard Meister, Lenzig AB, Austria

8.50 Paper recycling in Denmark - policy and impacts
Dr. Michael Linddal, Royal Veterinary and Agricultural University, Denmark

9.10 LCA - inventories of printing papers
Dr. Anssi Kärnä, Finnish Pulp & Paper Research Institute (KCL), Finland

9.30 Economic and environmental impact of paper recycling
Prof.Dr. Lars Lönnstedt & Dr. Stig Byström, Swedish University of AgriculturalSciences, Sweden

9.50 Coffee break

10.20	LCA for paper and paper products *Maryanne Grieg-Gran, International Institute for Environment and Development, United Kingdom*
10.40	Economic consequences of increased paper recycling in Norway *Erik Tromborg, Norwegian Forest Research Institute, Norway*
11.00	LCA for paper in Norway - an overview *Anne Ronning, STO, Norway*
11.20	LCA analysis of the pulp and paper industry in Sweden - an overview with particular refernce to paper recycling and technological development *Kenneth Libäck, SIMS, Sweden*
11.40	An overview of research in Finland related to economic and/or ecological consequences of increased paper recycling *Prof.Dr. Tapio Pento, University of Jyväskylä, Finland*
12.00	Life cycle inventories and joint time projections in national environmental planning *Tito Gronow, University of Jyväskylä, Finland*
12.20	Formation of working groups - specification of working tasks
12.40	Lunch break
14.00	Group work continues
17.00	Sightseeing Tour to Hamburg

Friday, 5 May 1995

8.30	Group work continues
9.30	Presentation of the results of the working group meetings (incl. clarifying questions)
11.00	Coffee break
11.30	Plenary session, Final discussion
13.00	Findings and recommendations of the workshop *Prof. Frühwald, Prof. Solberg*
13.30	Closing of the workshop

This workshop is sponsored by the European Commission, the Nordic Academy for Advanced Study and the Forstabsatzfonds, Bonn.

APPENDIX 2

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